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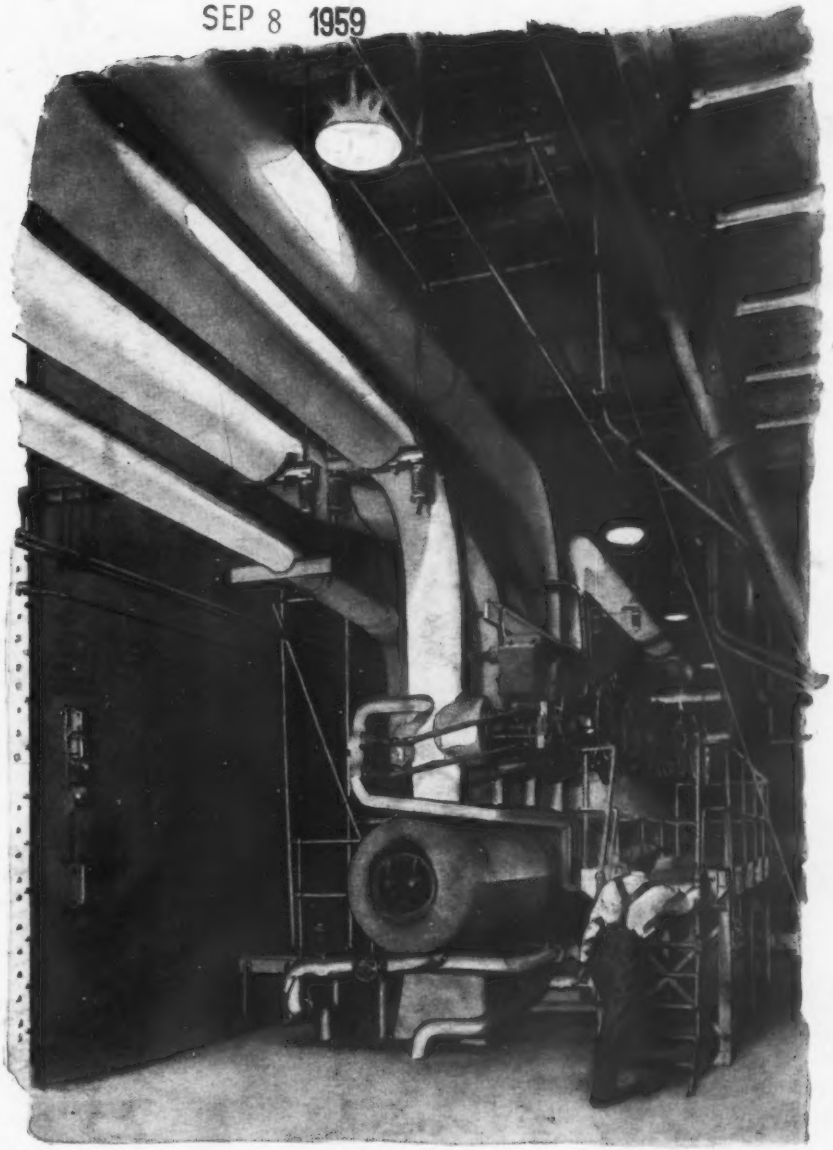

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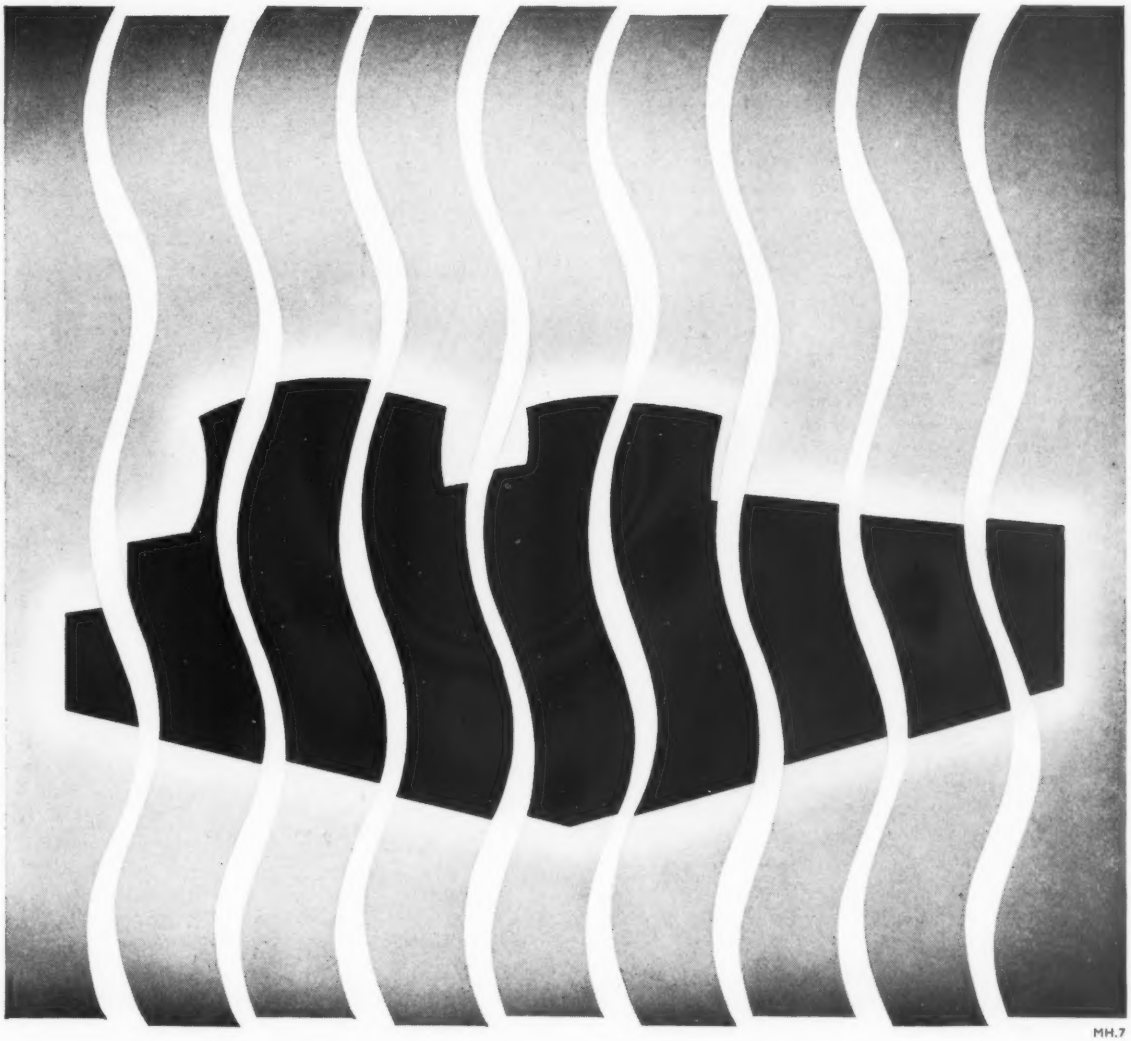

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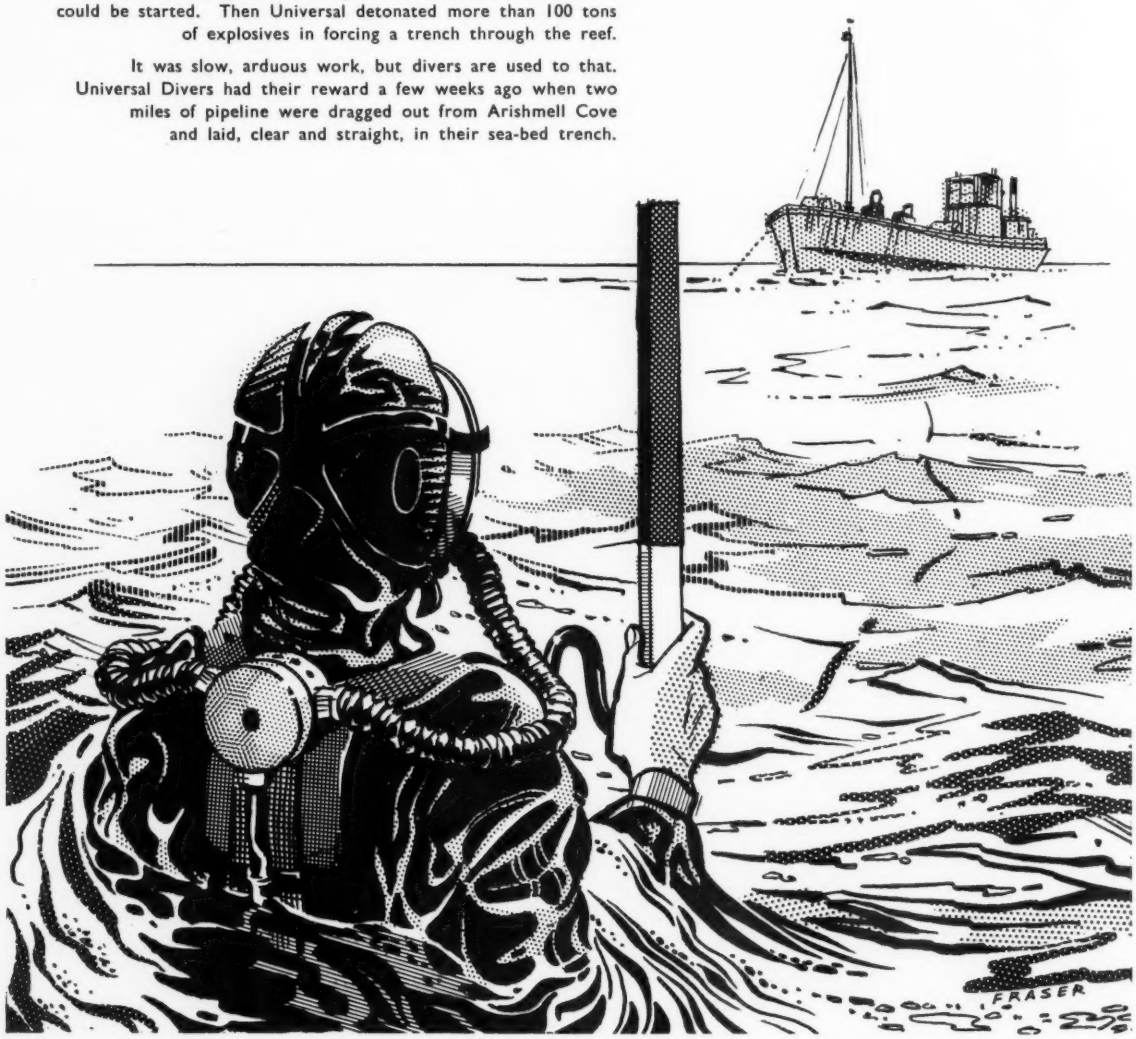

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The Winfrith Heath pipeline. In the background are the gates of Lulworth Castle.

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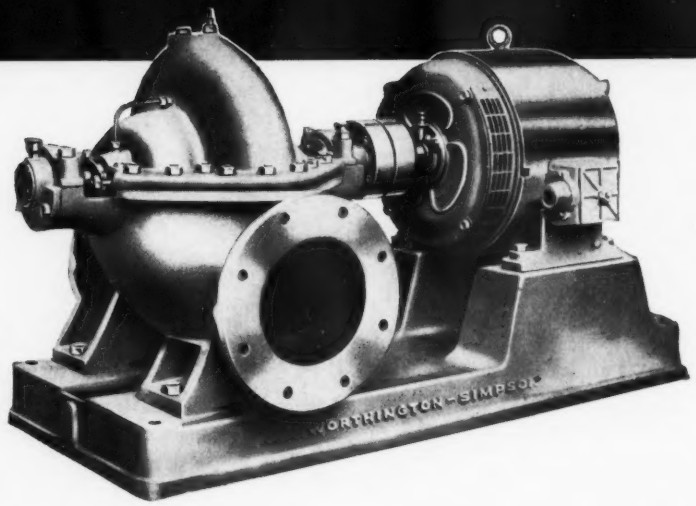

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NEWARK NOTTS

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THE United Kingdom Atomic Energy Authority's fast breeder reactor at Dounreay, Caithness, was due to go critical during August and a period of low power testing started. Power output will be stepped up in stages until 12 MW are reached by about June of next year. Maximum design output is 60 MW. The reactor is designed to be used as the experimental basis for a prototype industrial reactor using plutonium as fuel. Construction of such reactors on a commercial scale is expected to take place sometime in the 1970s. The Dounreay reactor is also designed to demonstrate the feasibility of highly rated liquid metal cooled reactors. The principal feature of the fast breeder is that the burning of one primary fissile atom is accompanied by the formation of more than one atom of a secondary fissile material by transmutation of in a fertile material. Initial fuel loadings in the Dounreay reactor will be of highly enriched uranium: plutonium will be used when it is readily available and the technology of its fabrication suitably developed. The fuel is clad in niobium-vanadium elements, two cladding materials being used in preference to one because of the need for meltdown safety device. Exotic metals are used to ensure that the cladding withstands the high temperatures (at a 60 MW power operation the fuel element temperature will be 800° C.) and corrosion effects of the sodium and sodium alloys coolants which will be used. Construction of the Dounreay reactor started in January, 1955. All civil engineering and major mechanical contruction were completed by the beginning of 1958. The reactor was handed over to the operating group at the end of that year, and commissioning started with electrical and mechanical testing of controls and instrumentation. Our illustrations show the night exterior view of the 135 ft spherical containment vessel and a view of the top of the reactor vessel within the sphere.

The Fast Breeder, Dounreay

12 MW planned by mid 1960

Winfrith A.E.E.

BRITAIN'S NEW N-RESEARCH CENTRE

Model showing principal buildings of the Winfrith AEE. These are the Zero Energy Halls (*top right*), the DRAGON project office (*background*), general services building, apprentice school and social centre (*top left*), reactor group offices (*centre*), and the waste treatment plant and ancillary buildings (*lower centre*). There are also the stores (*bottom left*) and site offices (*bottom right*). Reactors, to be installed when required, will be grouped in a semicircle around the permanent buildings.

WINFRITH is the latest research centre of the United Kingdom Atomic Energy Authority. Work undertaken there will include the study of new ideas leading to basic design data applicable to power generation and the operation of reactor experiments and small prototype systems. Research and development work will be primarily in the physics and engineering fields: basic development work in chemistry, metallurgy and nuclear physics will continue at Harwell.

Construction of the Winfrith Atomic Energy Establishment started two years ago. Facilities already installed are a PACE analogue computer, which is being used for dynamic studies of the operational behaviour of probable reactor studies; an exponential experimental set up for the High Temperature Gas Cooled (HTGC) reactor programme; and ZENITH, the zero energy high temperature gas cooled reactor also to be used in connection with this programme. (Details of the reactor and the HTGC programme are given on pages 440 and 441).

ZENITH, which was originally built for application in the Authority's own HTGCR programme, will be available to the OEEC team working on the DRAGON Project. DRAGON will be a 10 MW high temperature gas-cooled reactor (*see* NUCLEAR ENERGY ENGINEER, April, 1959) developed and operated by scientists from 12 European countries. It is to be built at Winfrith and at the end of the five years the project lasts, will become the property of the United Kingdom.

DRAGON will be the first reactor experiment at Winfrith.

BICEP, the long-term research programme carried out between the Atomic Energy Authority and four of the industrial nuclear energy consortia is to be moved to Winfrith. Staff and equipment are at present at Harwell.

Plutonium Research

Later, work on developing means of using plutonium as fuel will be started and appropriate experimental installations built. These will include exponential assemblies and a source reactor to drive them. A design for this source reactor is now being studied.

The basic studies on gas-cooled systems will need a further zero energy assembly, space for which is already available in the group of buildings in which ZENITH is housed.

Nuclear Propulsion

Another large area of work to be carried out at Winfrith when space permits concerns the exploration of the possibilities of reactor systems which might be suitable for use under load factor conditions lower than is the case with present large base-load power stations, and with the possibilities of nuclear propulsion. Basic and preliminary studies on boiling water reactors, steam cooled systems, and organic liquid moderated reactors will be made. Engineers and scientists from the British Shipbuilders Research Association will co-operate with the Authority staff on some of these projects.

Present staff at Winfrith is about 800. This will rise to about 2,500 in three years time.

Winfrith A.E.E.

Construction Work So Far

THE Winfrith Atomic Energy Establishment is situated in peaty heath country about midway between Poole and Dorchester, and 4½ miles from the sea coast. The site takes the form of a shallow saucer with a predominantly flat section in the centre. The initial area to be developed measures about 1½ miles by about 1 mile.

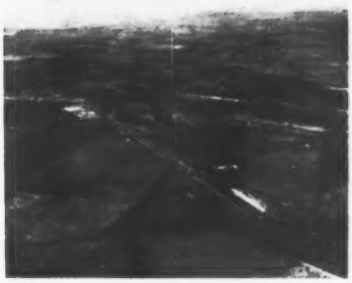
In laying out the site, the designers had to consider three principal problems. These were:—

1. Planning of the central area of the site in which the administrative, laboratory and workshop buildings would be placed;

2. Planning of the effluent pipe line; and

3. Planning of the future reactor experiments and reactor sites.

In addition, there were the usual problems of drainage, water supply, and power supply, of sewage disposal and of access to the site to contend with. The desirability of grouping radioactive and non-radioactive buildings apart had also to be taken into account.



(*Above*) View of the Winfrith AEE site early this year showing the Zero Energy Hall No.2 and Zero Energy Administration (*lower centre*) the general service building and apprentice school (*lower right*) central technical building and reactor group offices (*centre*) and waste treatment plant (*top*). (*Right*) View of the site in February, 1958

Other factors influencing the designers included the wishes of the Dorset County Planning Committee that the buildings should as far as possible blend into the landscape of the heath. Also, to obtain a sense of intimacy felt to be appropriate to a research establishment, it was decided that the buildings should be of a semi-domestic nature both in scale and character.

The first work to be carried out on the site was the building of the main road network, together with the surface drainage system, and erection of temporary site offices. A labour camp was established at a disused RAF camp between Winfrith and Dorchester.

Finished Buildings

Buildings now completed include one of the ZERO energy halls, of which there are to be two, the apprentice training school, the reactor group building and the engineering section of the central technical building. Also completed is the hexagon shaped social centre and community with its spire, the main entrance building, sub-stations, telephone exchange, ambulance and fire station.

Two principal buildings under construction are the canteen and the DRAGON project offices. At the same time work is proceeding on the effluent control area.

Mr D. W. Fry

Before becoming head of Winfrith AEE, Mr. Fry, MSc, MIEE, was chief physicist at Harwe l and later deputy director. Born and educated at Weymouth, which is not very far from Winfrith, Mr. Fry has been in the nuclear field since 1946, when he was in charge of particle acceleration research at the TRE, Swanage

THE DIRECTOR and DEPUTY DIRECTOR

Dr. J. V. Dunworth

Dr. Dunworth, CBE, MA, PhD, AMIEE, the deputy director of Winfrith, has had wide experience in nuclear matters having been head of the reactor physics division, the reactor division and deputy director of research policy at Harwell and member of the Canadian National Research Council Atomic Energy Project

Winfrith A.E.E.

Paving the Way for DRAGON

Zero Energy Hall No. 2 in which ZENITH is installed

TWELVE countries are participating in the DRAGON project to be centred at Winfrith. They are Austria, Belgium, Denmark, France, Italy, Luxemburg, the Netherlands, Norway, Sweden, Switzerland, United Kingdom and Western Germany. The project covers a period of five years starting from April 1st, 1959. Expenditure over this period may amount to as much as £13,600,000. Ten million pounds will be shared between the countries taking part and the balance, of up to £3,600,000 will be paid by the United Kingdom, who will have the right to acquire any installation or equipment built for the project after it is over.

The objectives of the project are twofold. Firstly, to carry out a programme of research and development work on high temperature gas cooled reactor systems, and secondly, to design, construct and operate a reactor experiment embodying the results of the research and development work.

In the reactor likely to be built at Winfrith, the fuel elements will by cylindrical and consist of "impermeable" graphite cans containing the fuel inserts. Helium gas will be used as the coolant, which will enter the heat exchangers at a temperature of 800°C. and leave at a temperature of 350°C. Power output of the reactor will be 10 MW.

The main technological problem of this type of reactor is the development of materials suitable for use at high temperatures, both in the fuel elements and in other parts of the reactor. These technological developments have to be tested under irradiation conditions and obtaining the necessary facilities is one of the major problems of the project.

Britain's Own Work

The United Kingdom has had its own programme on high temperature reactor systems for the past two or three years and has constructed or is constructing certain special facilities needed for this work. One of the facilities already installed is ZENITH, the zero energy high temperature gas cooled reactor designed and constructed under the supervision of the Authority by the GEC, Ltd. This reactor will be made available to the scientists working on the DRAGON project and will be used to check the reactor physics design calculation carried out for the reactor experiment.

ZENITH Features

In the past, experiments to study power reactor designs have been carried out in zero energy reactors operating at room temperature; although this is satisfactory for modest reactor temperatures the degree of extrapolation involved in assessing the behaviour of high temperature systems is unacceptable. ZENITH will operate under temperature conditions similar to those expected in a high temperature reactor.

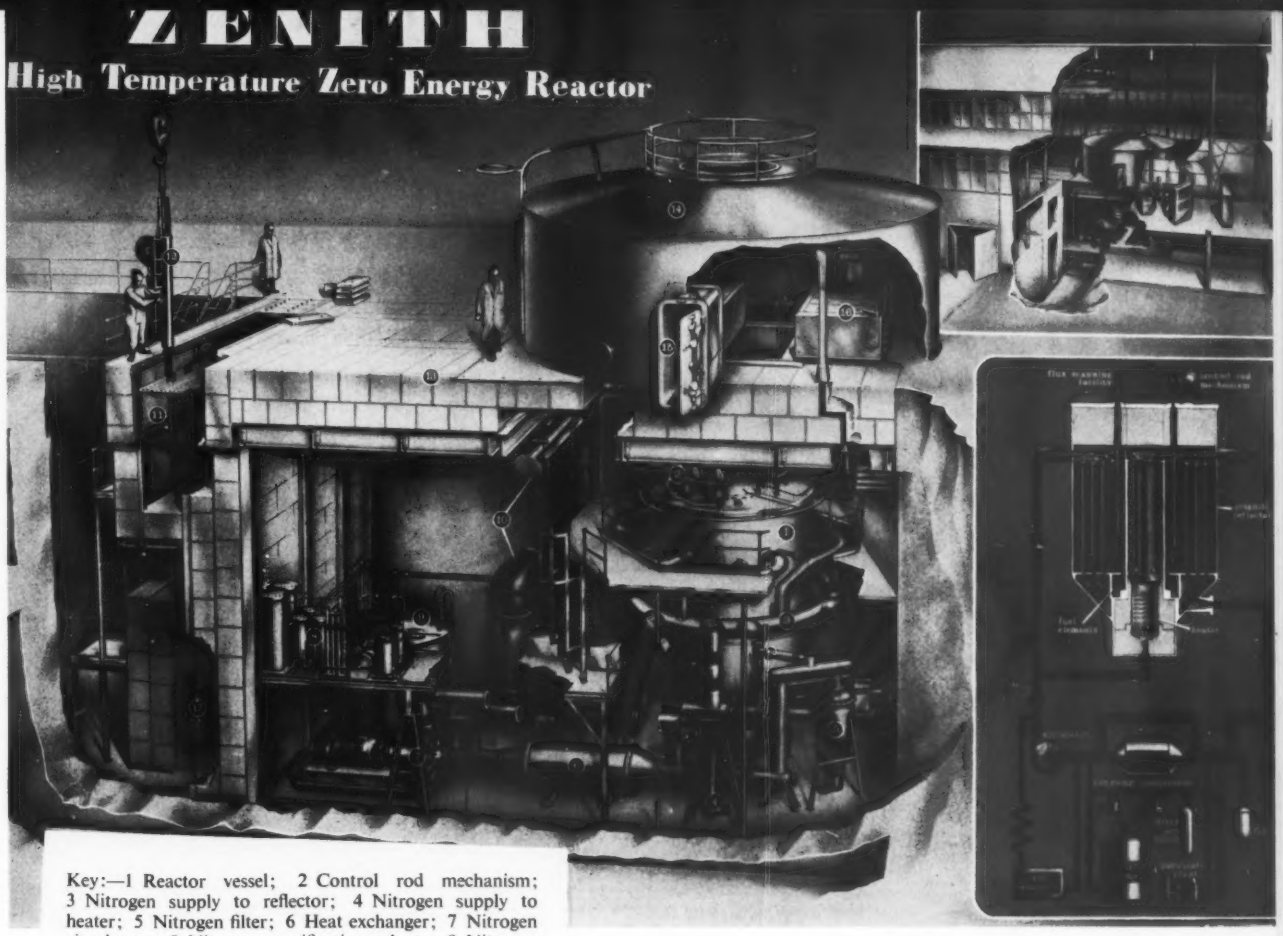
Fuel elements to be used in ZENITH will consist of graphite sleeves containing pellets of thorium oxide, uranium oxide and graphite. Nitrogen gas heated by means of a 250 kW heater will be passed through the reactor to raise the core temperature to 800°C. At the top of the core the hot nitrogen will be mixed with a cooler gas before it is passed through the reflector, to keep the reflector at a maximum temperature of 400°C. The maximum nuclear power of the reactor will be 100w, which is high enough for nuclear physics measurements to be made and low enough to avoid inducing such high activities in the fuel that rearrangement of the core would be difficult to carry out.

Another facility connected with the high temperature reactor programme is the exponential assembly used for measuring the properties of reactor core arrangements that will later be used in ZENITH.

Engineers check up the position of a component of the ZENITH reactor during its installation

ZENITH

High Temperature Zero Energy Reactor

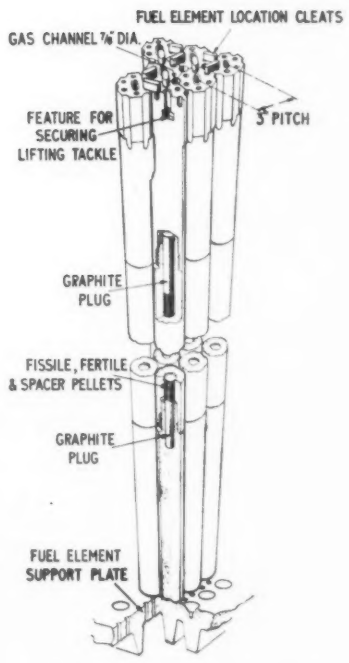


Key:—1 Reactor vessel; 2 Control rod mechanism; 3 Nitrogen supply to reflector; 4 Nitrogen supply to heater; 5 Nitrogen filter; 6 Heat exchanger; 7 Nitrogen circulator; 8 Nitrogen purification plant; 9 Nitrogen gas holder; 10 Waste heat ventilation system; 11 Fuel element store; 12 Load unload flask; 13 Concrete block shield roof; 14 Containment dome; 15 Air lock access to dome; 16 Shield trolleys; 17 Labyrinth entry to contained space.

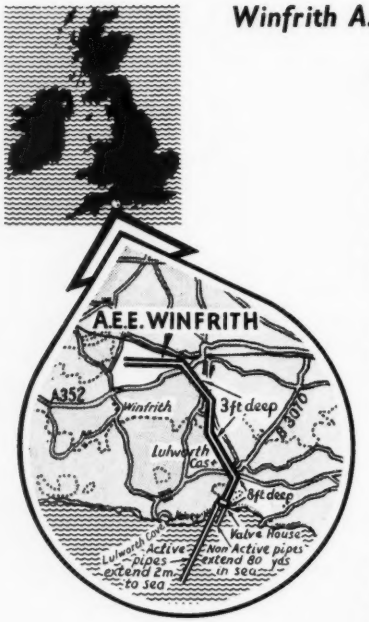
Design and Performance Characteristics

Core height less reflector	4 ft
Core diameter less reflector	4 ft
Height over reflector	8 ft
Diameter over reflector	10 ft 6 in. nominal
Weight of reflector	26 tons
Thermal-radiation barrier (between core and reflector)	Lampblack
Type of fuel element	Enriched-uranium and thorium ceramic discs with graphite spacer discs inside graphite tubes.
Moderator	Graphite of the fuel-element tubes.
Number of fuel elements in core	235
Maximum thermal-neutron flux	10^{6}n/sq.cm/sec
Maximum nuclear power	100w
Lattice pitch	3 in. triangular
Control	By neutron-absorbing rods at the inner edge of the reflector.
Heating and cooling medium	Nitrogen
Gas inlet temperature to heater	400°C. maximum
Gas outlet temperature from heater	950°C. maximum
Normal maximum working gas flow	3,000 lb/hr
Cooling-down gas flow	10,000 lb/hr
Working gas pressure	18 in. swg
Cooling-down time	48 hr
Heating-up time	48 hr

Contractors for the detailed design and supply of ZENITH are the GEC Ltd. The basic concept and overall design of this reactor and its fuel element, however, have been the work of the United Kingdom Atomic Energy Authority, who have throughout supervised the design and manufacture of the plant.



Sectional drawing of fuel elements for ZENITH. There are 235 of these in the core, arranged on a 3 in. triangular lattice pitch. Each element consists of a large number of enriched uranium and thorium ceramic discs, together with some graphite spacer discs, all contained within a graphite tube



Winfrith A.E.E.

The Waste Pipeline

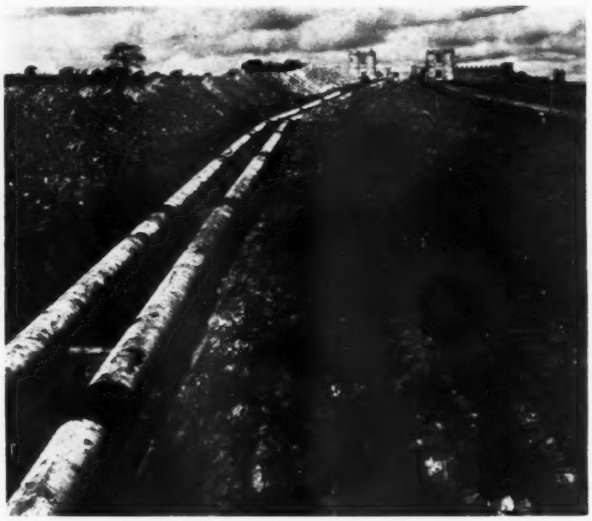
RADIOACTIVE effluents from the Winfrith Atomic Energy Establishment are to be discharged two miles out at sea. They will be carried in a twin-pipeline, much of which has already been laid.

The overland portion of the pipeline, which is just over four miles in length, consists of two sets of concentric pipes. The inner pipe carries radioactive wastes, the outer annulus non-radioactive materials. Automatic monitors placed in the outer annulus will detect any radioactive matter that leaks from the inner pipe.

The pipeline is buried 3 ft in the soil except when it travels under the Royal Armoured Corps gunnery range where it is buried at a depth of 10 ft.

At sea edge, concentric pipes are split into two separate pipes, the pipes for non-radioactive matter reaching out at sea no further than 50 ft beyond low water spring tides.

The distance of two miles for discharging the radioactive materials was chosen on the results of extensive tests carried out by the UKAEA in 1956 under the project name of EXERCISE MERMAID.



(*Left*) Map showing the route of the Winfrith radioactive waste pipeline. (*Right*) Part of the pipeline at the entrance to Lulworth Castle

Designers, Contractors and Equipment Suppliers

Selection of a site and the preparation of sketch designs for the establishment were undertaken by engineers from the AERE, Harwell, and architects and engineers from the Ministry of Supply. After official permission was given to the building of the station, design and construction of the buildings and civil engineering works became the responsibility of the Works and Building Department of the Industrial Group of the UKAEA, which acts as agents to the Research Group

Among firms holding contracts and supplying equipment for the Winfrith project are:—General Electric Co., Ltd. (the ZENITH reactor); Turiff Construction Corporation Ltd. (main civil engineering contract); W. E. Chivers & Sons Ltd. (preliminary civil engineering work); Constructors John Brown Ltd., Taylor Woodrow Construction Ltd., in association with Collins Submarine Pipelines (effluent pipeline); Universal Divers Ltd. (sea bed survey work); Spencer and Partners (consultants for cathodic protection of pipeline); Armstrongs Cork Co., Ltd., Leyland Rubber Co., Ltd., Turners Asbestos Co., Ltd., Universal Asbestos Co., Ltd., Permutit Co., Ltd. (water treatment plant); A. Reyrolle & Co., Ltd., English Electric Co., Ltd., Crompton Parkinson Ltd., Walsall Ltd., Power Centre Ltd. (electrical equipment); British Insulated Callender's Cables Ltd., Scottish Cable Co., Ltd., Metropolitan Cable Ltd. (electric cables); ICI (Paints) Ltd., Lewis Berger (G.B.) Ltd., Murray & Jones Ltd., Farrow and Ball Ltd., North British Chemical Co., Ltd., W. & J. Leigh Ltd. (paints); Evershed & Vignoles Ltd., Honeywell Controls Ltd., Appleby & Ireland Ltd., Foxboro-Yoxall Ltd., Tylors Ltd., Cleveland Meters Ltd., Leeds Meters Ltd. (instruments); Britmac Ltd. (switch and socket equipment); Simplex Ltd. (distribution boards); Dennis Ferranti Ltd. (transformers); Stewarts & Lloyds Ltd. (steel pipes); Stanton Ironworks Co., Ltd., Staveley Iron and Chemical Co., Ltd. (cast iron pipes); Burnden Park Engineering Co., Ltd., Steels Engineering Installations Ltd. (M.S. flanges); J. S. & F. Folkard Ltd., Chemical Pipe & Vessel Co., Ltd. (polythene pipes); Mendip (Chemical) Engineering Ltd. (reinforced resin pipes); Nordac Ltd., Dunlop Rubber Co., Ltd. (rubber lines M.S. tanks); Newton Chambers & Co., Ltd. (lithcote-lined main service tanks); R. Jenkins & Co., Ltd. (main service tanks); Sigmund Pumps Ltd., Sulzer Bros. Ltd., British Labour Pump Co., Ltd., Broadwell Engineering Co., Ltd., Gwynnes Pumps Ltd. (pumps); J. K. Innes & Co., Ltd. (stirrers); W. E. Farrer Ltd. (sewage disposal plant); Glenfield & Kennedy Ltd., Guest & Chrimes Ltd., J. Blakeborough & Sons Ltd., Allen Harrison & Co,, Ltd., Jones, Tate Ltd., & Co., Hamilton Woods & Co., Ltd., British Steam Specialties Ltd., A. Heaton & Co., (Valves) Ltd., Shiphams Ltd., Saunders Valve Co., Ltd. (valves); John Thompson-Kennicott Ltd. (water treatment plant).

The Royal Military College of Science

TEACHING NUCLEAR SCIENCE IN THE ARMY

by

C. G. Wilson, MSc, AInstP

and

D. K. Thomas, BSc, AInstP

South view of the Royal Military College of Science

FROM small beginnings in the middle of the last century, when the shortcomings on the technical side in the British Army were troubling the more progressive of its officers, there has evolved by various stages the extensive Royal Military College of Science of to-day, set in ideal surroundings in Berkshire.

The College on its present site dates from 1946, when it was remodelled to meet the challenge of the tempo, scale and technological aspects of modern war. Run on the lines of a residential university, courses are provided for young officers reading for degrees in science or engineering, while specialized courses cater for more mature officers. A limited number of civilian students holding Ministry of Supply Studentships are also accepted annually.

London Degrees

The younger students pursue a normal three-year course in engineering, mathematics, physics, or chemistry, leading to external degrees of the University of London. The remainder of the students attend a range of courses whose length varies from one to seven academic terms. The content of these courses is designed to teach the principles of science and engineering in relation to their application to modern weapons and to other requirements of the Army.

About five years ago, the growing importance of nuclear weapons and of nuclear science and technology in civilian industry was recognized by an acceleration of the growth of the teaching of nuclear physics and chemistry and their extension to associated technologies. The present position is that *all* students at Shrivenham have a course on nuclear science at a level appropriate to their main course. In addition there is a post-graduate nuclear science course of about four months' duration open to all three Services and to the Ministry of Supply.

Converted Hut

The efficient teaching of nuclear science requires a properly designed laboratory in order to give practical acquaintance with nuclear radiations and their various properties. To avoid the delay associated with the construction of a new building, a large Romney hut was converted at a fraction of the cost. This, named the Rutherford Laboratory, was designed primarily as a teaching laboratory and has been described elsewhere[1].

The main laboratory conversion included a false aluminium ceiling and false walls covering service ducts; careful attention was given to exposed wall and furniture surfaces, so that contamination by radioactive material could easily be removed. All chemical manipulations are carried out in stainless steel trays lined with tissues, and appropriate apparatus ensures that at no time is contact made between radioactive sources and the hands or mouth. Particular care is paid to monitoring the laboratory and to making certain that students respect the health dangers of nuclear materials. As this laboratory is capable of catering for only 30 students at any one time, a less specialized laboratory, suitable for completely enclosed sources, has been established in a neighbouring building.

The aim of all the nuclear science teaching at Shrivenham is to acquaint the students with the fundamentals of nuclear physics and chemistry and the associated technologies, so that the principles of nuclear weapons and their effects, and the design and operation of nuclear power plants, are fully understood. This is a fairly straightforward task with the post-graduate courses, and the original laboratory experiments were designed for these courses. For other courses, in which nuclear science is supplementary to the main course and can take up only a fraction of the time allotted to it, special short courses of lectures and practical classes are arranged, the contents being tailored to suit the academic level of the course and the time available.

Planning Vital

To overcome the restrictions of space and the different academic levels of the shorter courses, care in the design and planning of experiments is essential: for example, commercial counting equipment is provided so that little time is wasted

in setting up experiments. The provision of equipment is good and this includes a number of standard commercial Geiger-Muller counting units, a proportional counter, a gamma ray scintillation counter, a single channel γ-ray spectrometer and two γ-radiography units. In addition, there are items of local design and construction, which include a "thin lens" magnetic focusing β-ray spectrometer. Many types of radioactive source are available including two moderately strong iridium-192 sources (nominally 2 curies) for γ-radiography, an antimony-beryllium neutron source (1 curie) and a 20 mgm radium-beryllium neutron source.

Irradiation Tests

The laboratory experiments are designed to emphasize the principal properties of radioactive radiations, with particular reference to their effects on materials, the technique of shielding, radioactive contamination, and possible military and industrial applications of radio-isotopes. These experiments include range and energy measurements of alpha-, beta- and gamma-rays, using various counting techniques, the effects of neutron irradiation and neutron flux measurements. The experimental schedules are produced in various versions so that basically the same experiment can be adapted to various levels of experience as, for example, by the use of direct-reading instruments for measuring counting rates instead of counting over a given time.

Experimental research in the present building is limited by space, but some projects of military significance have been successfully carried out. The importance of nuclear science teaching at Shrivenham has been emphasized by the appointment of Dr. A. Charlesby as Professor of Physics, an acknowledged expert in the field of the effects of nuclear radiation on materials.

Construction work for a new radiation laboratory has recently been started, and this will house, initially, a 1,000 curie cobalt-60 γ-ray source. With this facility it is intended to initiate a comprehensive and co-ordinated research programme into the effects of very high intensity radiation on a variety of materials including long-chain polymers. In particular, studies will be made of the electrical and thermal conductivity, viscosity, spin resonance, etc. The aim of these researches is to throw light on the complex mechanisms responsible for the biological damage caused by nuclear radiation.

Spectrometer Work

In addition, some work is already in progress on certain effects of alpha-, ultra-violet and X-radiation on materials. Another aspect of atomic and nuclear physics is represented by a curved crystal (mica) γ-ray spectrometer, now under construction for the precise measurement of the energy and intensity of X-rays and low energy γ-rays emitted in nuclear decay.

Linked with these studies are other investigations in the field of solid state physics, some on crystal structure and some, under Associate Professor A. J. Woodall, on the properties of the unusual metal gallium with its outstandingly anisotropic behaviour.

Professor A. CHARLESBY, DSc, PhD, DIC, FInstP, professor of physics at the Royal Military College of Science since 1957, was formerly head of the radiation department in the Research Laboratories at Cambridge. From 1949 to 1955 he was at Harwell and before that held scientific posts with the Air Ministry and the German Occupational Forces. Dr. Charlesby is on the panel of international editors of NUCLEAR ENERGY ENGINEER.

The Army's nuclear teaching centre at Shrivenham is not part of a normal Service training establishment but of an educational institution at a high academic level. The facilities available are excellent and, with the well-qualified staff, the centre may well be the envy of those who are striving against the national scarcity of suitably trained personnel. Although the military importance of nuclear science and technology is at no stage forgotten, the basis on which the subject is taught conforms to the proper university spirit of inquiry. The Army has, of course, complementary establishments to deal with training and other predominantly military aspects. It is hoped that this policy ensures that Shrivenham graduates at all levels can think and speak about nuclear science. These officers, throughout their service careers, should find their knowledge and experience in this branch a valuable asset.

Reference

[1]WOODALL, A. J., WILSON, C. G., JONES, A. L., and THOMAS, D. K., "The design and management of a nuclear laboratory." *Nature*, 182, 367, 1958.

The Rutherford Laboratory, R.M.C.S., a converted Romney hut—(*Left*) radiochemistry section; (*Right*) nuclear physics section

ZGS—America's Latest Synchrotron

$29m Plant to Accelerate Particles to 12·5 BeV

CONSTRUCTION of a 12 BeV proton synchrotron at the Argonne National Laboratory, Lemont, Illinois, has started. When completed, the machine will be able to produce all 30 known and anticipated sub-atomic particles, and in such quantities to enable their properties to be determined with precision.

To be known as the Zero Gradient Synchrotron (ZGS), the machine will be housed in a 200 ft diameter ring-shaped building covered with an earth mound. Arranged on the outsides of the circle will be a 4,000-ton magnet, in eight sections, through the centre of which will be a rectangular aperture for the protons. The earth mound will act as a shielding against possible radiation during operation of the machine.

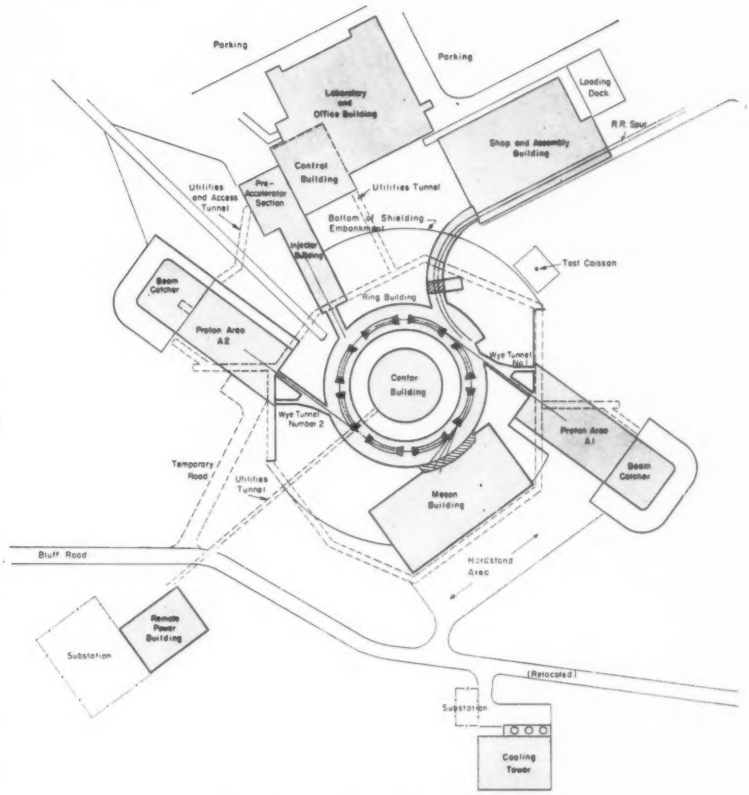
Pre-Accelerated

Protons will first be accelerated to 800 kV by a standard high voltage source. From there they will go into a 50 m MeV linear accelerator which will introduce the protons into the synchrotron via bending and focusing magnets in short well-regulated bursts. Like the synchrotron, the linear accelerator will be covered with earth.

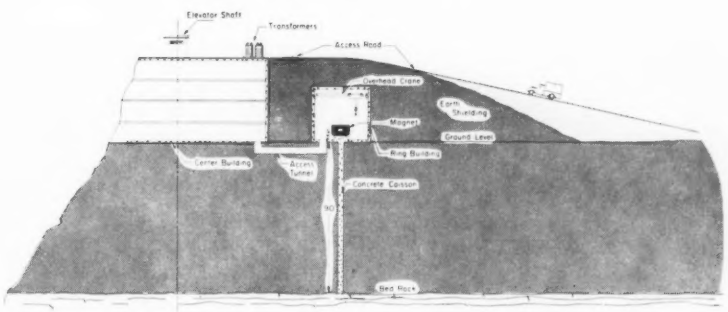
When the 50 MeV protons are injected into the synchrotron magnet, the magnetic field will be very low, about 500 gauss. It will then be stepped up—the maximum value of 21,500 gauss being attainable within one second. The protons are accelerated around the machine through a high frequency cavity which is so constructed to enable the frequency and voltage to be controlled. In this way the particle energy can be increased in step with the magnetic field.

Removal For Experiments

Upon reaching the maximum energy of 12.5 BeV, or at any other time before this, the high energy protons will be removed from the machine into one of the two experimental areas. In addition to these, there will be a so-called meson area.



Initial layout of the ZGS Facility at Argonne



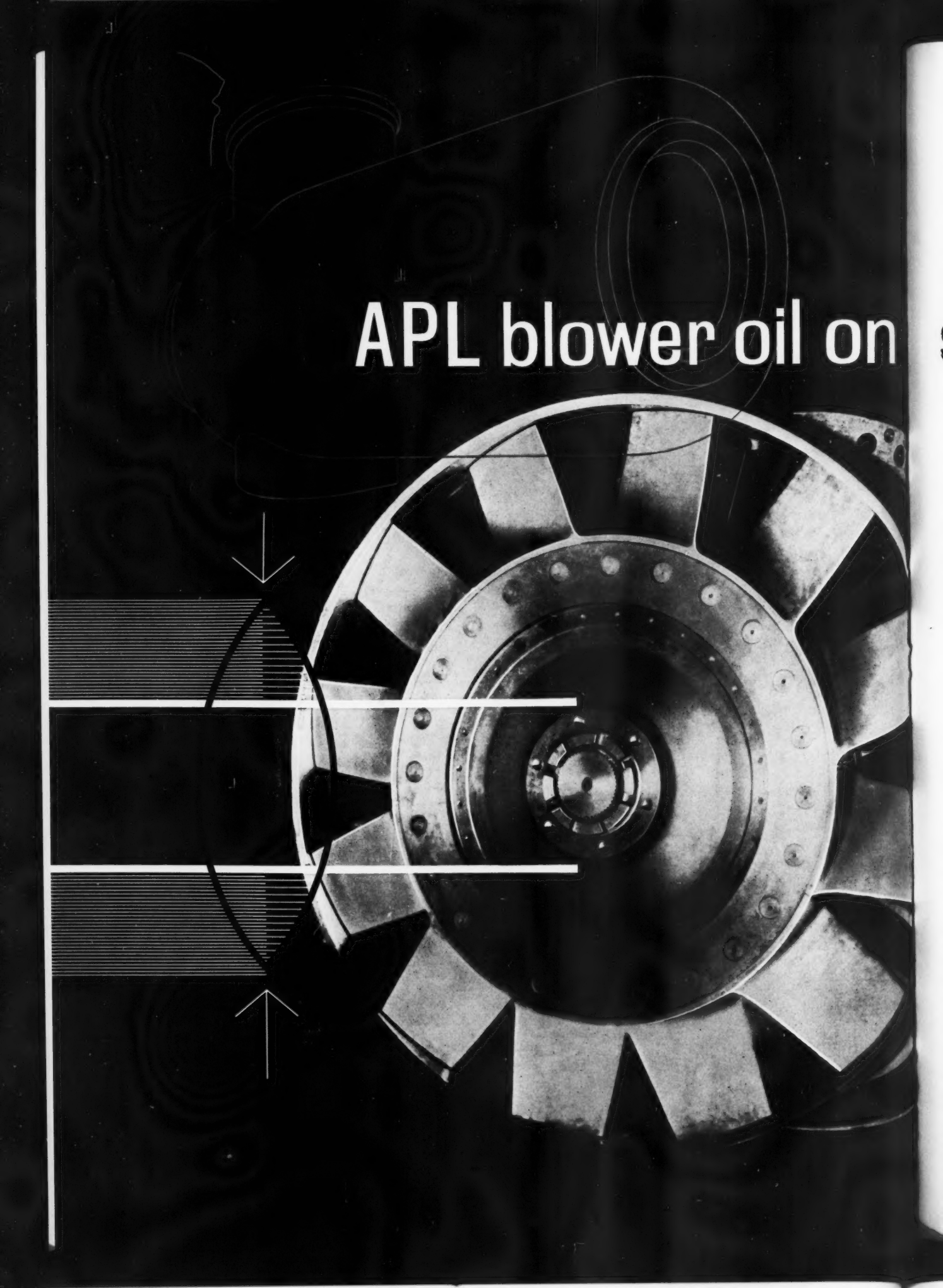
Drawing to show earth shielding and foundations of magnet. It is supported on 39 in. diameter concrete caissons sunk 90 ft in the ground to bed rock

This will be a large room, 100 ft × 200 ft, separated from the synchrotron by a 12 ft thick steel wall.

The machine and associated buildings and equipment will cost about $29m.

Material and drawings used in this article are supplied by the Argonne National Laboratory, which is operated by the University of Chicago for the U.S. Atomic Energy Commission.

APL blower oil on



n sentry-go at Bradwell...

The crucial points of the high pressure CO_2 coolant circuit at Bradwell will be the blower shaft seals. Every minute of every working day Shell APL blower oil will guard these escape points—being continually pumped into the seals and bearings, led away, purified and recirculated.

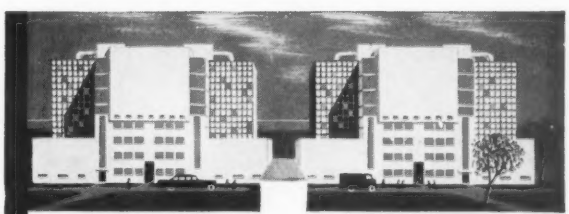
This very remarkable oil presents a two-way seal. Outwards, there is a minimum CO_2 loss as the oil has the lowest possible gas solubility. Inwards, in spite of the heat of the gas, oil vapour contamination is negligible thanks to the extremely low vapour pressure of the oil.

The research that went into APL blower oil is characteristic of the way Shell set about doing things. It was conducted at Shell's Research Centre at Thornton in close collaboration with the U.K. A.E.A. and the blower manufacturers. In the course of much fundamental research, a wide range of oils was subjected to vapour pressure and gas solubility tests in the laboratory. Selected oils from this range were used in the bearings and seals of a blower rig. In 1956, after four years of research, the finished product joined the Shell Atomic Power Lubricants range—marketed under the name of Shell APL 729. This oil has been in use at Calder Hall since the autumn of 1956.

The moral of the story is that Shell research is supremely applicational. The Centre at Thornton is always ready to work with even the most specialised sectors of industry to produce the right oil for the job. If you and your organisation have any major lubrication problem it pays to get in touch with your local distributor of Shell Industrial Lubricants.

The Research Story

Though the sealing action demanded of Shell blower oil is common in other industrial equipment such as hydrogen-cooled alternators, there were quite a few additional problems. It was necessary for the oil to have long life, low vapour pressure, low gas solubility, good thermal stability and high film strength —to be able to withstand high temperatures and to be resistant to all kinds of corrosive influences, including carbonic acid. The crux of the research was to combine all the above requirements into one oil, in order to minimise back diffusion of molecules which would contaminate the reactor.



BRADWELL NUCLEAR POWER STATION. AN ARTIST'S IMPRESSION

SHELL

ATOMIC POWER LUBRICANTS

another proof of Shell leadership in lubrication

For High Temperature Protection

NEW CERAMIC COATINGS

NUCLEAR and ceramic scientists of the U.S. National Bureau of Standards have recently developed an entirely new type ceramic coating material of exceptionally low thermal neutron absorption coefficient in order to meet the increasing demand for high-temperature protection of alloys in nuclear reactors. The new ceramic material is the result of an investigation involving over a couple of hundred ceramic coating mixtures.

In atomic piles that are made to operate at high temperatures, the use of ceramics or metal-ceramic combinations generally offers the only alternative to the use of bare metals for shields, moderators and fuel rods. Most promising of these materials are boron-free coatings of the frit-refractory type in which a high-barium frit is combined with ceria-chromic oxides.

The nuclear property that chiefly determines the suitability of a ceramic coating for pile construction is its low absorption of neutrons when the material is placed in the path of a neutron beam. The common ceramic coating contains boron, which may be introduced as borax or as boric acid. So far as ceramic considerations are concerned, there is no objection to boron. However, this element has an unusually large neutron capture cross section. A ceramic material assigned for use as a moderator would therefore be quite unacceptable if it contained significant amounts of this element.

Sights Set

Early in the programme a goal was established for the maximum value of the absorption coefficient of the ceramic coatings: this value should not exceed that of the alloy to which the coating was to be applied. A survey of published data of the elements indicates that the most commonly used heat resisting alloys have thermal neutron coefficients ranging from 2.5 to 20 barns.

On the basis of these data, a value of three barns appeared to be a reasonable maximum to set for the coatings, although it was considered desirable to keep the coefficient as low as practicable. The major constituents in the ceramic coatings were therefore limited to those elements having coefficients of three barns or less; minor constituents were limited to 10 barns or less.

Modifications Used

The problem of developing these new coatings was attacked through systematic alteration of the composition of the Bureau's coatings A-417, A-418 and A-19, primarily by eliminating boron with its neutron absorption coefficient of 740 barns. Coating A-417, which contains 70 parts of frit 331 and 30 parts of chromic oxide, was originally developed for the protection of high-temperature alloys such as type 321 stainless steel and Inconel. The Bureau's coating A-418 is similar to A-417 except that it contains frit 332, which is free of beryllium oxide, instead of frit 331 and for this reason has largely replaced A-417 in commercial use. The Bureau's coating A-19, which contains 80 parts of a groundcoat enamel frit plus 20 parts of alumina, was developed for the protection of low-carbon steel at temperatures up to 1200°F., but it has also found application for protection of some of the high-temperature alloys at higher temperatures.

During the course of the investigation, frits were designed and smelted in which various oxides were substituted for B_2O_3 NBS frit 331 (Table I) and its modification, NBS frit 332. The most successful were those in which $Zn_3(PO_4)_2$ and $Ca_3(PO_4)_2$ were substituted for B_2O_3. Frits containing appreciable quantities of CaF_2 severely attacked the refractory crucibles in which they were smelted, but frits that contained neither CaF_2 nor a phosphate were in general difficult to melt.

Tests of coatings on a number of metals indicate that those containing the newly developed frit 435 were outstanding in the protection they afforded the various alloys; but several hours or days after completion of an extended heating test,

Table I.—Frit Compositions, in Mol per cent.

Material	Base Frit No. 331	Experimental Frit No. 435	452	453	454	455
SiO_2 ..	50.80	51.02	46.02	43.52	41.02	46.55
TiO_2 ..	—	—	5.00	7.50	10.00	5.00
BaO ..	23.04	25.51	25.51	25.51	25.51	25.77
B_2O_3 ..	7.49	—	—	—	—	—
CaO ..	5.72	6.12	6.12	6.12	6.12	9.28
ZnO ..	4.93	5.10	5.10	5.10	5.10	3.43
Al_2O_3 ..	—	—	—	—	—	—
ZrO_2 ..	—	—	—	—	—	—
BeO ..	8.02	10.20	10.20	10.20	10.20	6.88
P_2O_5 ..	—	2.04	2.04	2.04	2.04	2.04
Total ..	100.00	99.99	99.99	99.99	99.99	100.00
Average neutrons absorption (Barnes) ..	21.7	0.192	0.287	0.334	0.381	0.287
Fritting temp., °F.	2425	2600	2530	2460	2450	2450
Softening point, °F.	1385	1462	1474	1535	1562	1483

these coatings chipped from the austenitic stainless steels to which they were applied. This behaviour appeared to be due to stresses produced by differential thermal expansion. To increase the thermal expansion of the frits, TiO_2 was substituted for SiO_2, GeO_2 for SiO_2, and FeO for BaO. Increased thermal expansivity of the coatings was also obtained when CeO_2 was used instead of Cr_2O_3 as a refractory admixture with frit 435.

Found the Best

Of the numerous frits that were designed and smelted, the best results were obtained from frit 435 and its modifications. Compositions of the base frit, of frit 435, and of several other boron-free frits are given in Table I. This table also includes the computed average neutron absorptions for the frits, the fritting temperatures, and the softening points by the fibre deformation technique. While the substitution of TiO_2 for SiO_2 increased the softening point as determined by this method, it decreased the fritting temperature.

The computed average absorption coefficients for the various frits ranged between 0.15 and 0.25 barns, indicating that the boron-free frits were all satisfactory from this standpoint. The substitution of TiO_2 for SiO_2 increased slightly the neutron absorption of the frits, but it was still below 0.5 barns as compared to 3.0 barns or more for the base metal.

The raw materials used in the production of frits were all in powdered or in fine granular form, and the frits were prepared according to the usual laboratory procedures. Technical-grade oxides were used if available. When such oxides were not available, not stable in composition, or not readily soluble in the glass, the elements were added in the form of simple stable compounds.

Preparing the Samples

Water suspensions, or "slips," of the 200 coatings studied in this investigation were prepared by grinding in a ball mill a mixture of a frit and a refractory crystalline material with water and clay. The consistency of the slip was adjusted by the addition of water or electrolyte until a coating approximately 1 mil in thickness could be obtained by dipping a metal alloy sample into the slip. The dipped specimens were dried at 220°F. and then fired in a furnace for four minutes at the appropriate temperature—in the range of 1850°F. to 2250°F.

By Trial and Error

The most promising results have been obtained with coatings which contain cerium oxide or both cerium oxide and chromic oxide as the refractory addition. Tests in which the proportions of frit and refractory were systematically varied indicate that the optimum ratio was in the range of 65 parts by weight of frit to 35 parts by weight of refractory, although good results were obtained with a few coatings in which the proportion was 95 parts frit to 5 parts refractory. Most of the coatings contained 5 parts by weight of enamelling clay, used as a flotation agent. The mill batch for coating N-108, given in Table II, is typical of those used. None of the frits that were free of BeO showed promise in this investigation.

Table II.—Mill Batch for Coating N-108

Material	*Parts by weight* (gm)
Frit 435	195
CeO_2	75
Cr_2O_3	30
Clay	15
Water	120

Mill 2½ hr in 1-qt. ball mill
(Approximately 15,000 revolutions of mill)

Most of the coatings that adhered well (Table III) were tested to evaluate the protection they afforded the various alloys in an extended heating test. In this test, the samples were heated to 1900°F. and cooled to room temperature a number of times in a series of irregular cycles. During the one-week trial, the samples were at the high temperature for a total of 150 hours. Under this test, none of the coatings was outstanding when applied to type 321 stainless steel, but coatings N-109, N-146, N-149 and N-89 gave appreciable protection. Coatings N-94, N-141, N-148 and N-151, in addition to the above, appeared to be in good condition at the end of the test on type 309 stainless steel. Most of these coatings, as well as N-70, N-73, N-140 and N-147, performed well when applied to type 310 stainless steel. Most of the coatings also showed good results when applied to Inconel.

Corrosion Inspection

Metallographic examination of tested and untested coated specimens revealed that some corrosion occurred beneath the coating in every case in the extended heating tests, but the amount or apparent depth of "stringer" corrosion was markedly reduced by the coating. Photomicrographs showed corrosion to a depth of approximately 1½ mils on uncoated specimens, and to less than half of this depth on specimens coated with N-89. In terms of cross sectional area of the stringers caused by corrosion, the difference between

(*Continued on page 454*)

Table III.—Compositions of Promising Coatings. Parts by Weight

Coating No.	Frit No.	Frit Amt.	Refractory Cr_2O_3	Amt. CeO_2	Clay Amt.	Firing Temp., °F.
N-70 ..	452	70	30.0	—	5.0	2100
N-73 ..	453	70	30.0	—	5.0	2100
N-89 ..	435	95	5.0	—	5.0	2075
N-90 ..	455	95	5.0	—	5.0	1880
N-94 ..	453	65	35.0	—	5.0	2165
N-95 ..	454	65	35.0	—	5.0	2165
N-108 ..	435	65	10.0	25.0	5.0	2120
N-109 ..	435	65	—	35.0	5.0	2075
N-140 ..	435	65	10.0	25.0	0.5*	2100
N-141 ..	435	60	—	40.0	5.0	2050
N-146 ..	435	75	—	25.0	5.0	2050
N-147 ..	435	65	2.5	32.5	5.0	2150
N-148 ..	435	65	5.0	30.0	5.0	2100
N-149 ..	435	65	7.5	27.5	5.0	2100
N-150 ..	435	65	12.5	22.5	5.0	2150
N-151 ..	435	65	15.0	20.0	5.0	2150

*Wyoming bentonite

N.S. *Savannah*

Reactor Physics and Core Design

by P. M. Wood and Z. Levine

Babcock & Wilcox Co., U.S.A.

SAVANNAH, the world's first nuclear powered cargo-passenger ship, was recently launched at Camden, New Jersey. She is powered by a single 74 MW pressurized water reactor, designed and fabricated by the Babcock & Wilcox Co., of America. Design data and illustrations were published in NUCLEAR ENERGY ENGINEER, *August, 1959.*

THE active core of the reactor for the *Savannah* is approximately a right circular cylinder, 61 in. in diameter and 66 in. high. The core is made up of 32 fuel elements, 8.9 in. square, and approximately 92 in. overall length, including end fittings. The fuel elements are confined within a semi-permanent "egg-crate" type lattice to provide the equivalent of a pressure can around each of the 32 fuel elements which are arranged in a square lattice on a 9.7 in. pitch. The "cans" have a 0.125 in. wall designed to withstand the pressure differentials which arise as a result of the multi-pass flow pattern. Reactivity control is provided by 21 cruciform-shaped control rods, 8.0 in. tip to tip with top mounted drives.

Unground UO_2

The fuel element design for the ship employs full length fuel rods. The individual rods contain unground uranium dioxide pellets, 0.4425 in. o.d., pressed and sintered to 85 per cent. of theoretical density. The cladding consists of a 0.500 in. o.d. type 304 stainless steel tube with 0.026 in. wall thickness. The gap between fuel pellet and tube wall contains helium gas which is introduced during the end plug welding process. Each fuel element contains 196 rods in a square array. Centre to centre spacing of the rods is 0.612 in., giving an overall metal to water ratio of 0.97. The rod spacing is maintained by small stainless steel ferrules brazed in place every 8 in.

The core and the thermal shields are supported by the core support skirt which is mounted on the vessel wall near the upper flow nozzles. The core is completely enclosed by the inner thermal shield and lower flow baffle.

The egg-crate lattice containing the fuel elements is confined between a lower and an upper grid plate, the latter serving also to provide a turn-around manifold from which the entire primary coolant flow is distributed into the 16 outer fuel elements.

Coolant Guided

Guide tubes below the lower grid plate serve as an extension of the fuel element cans, directing the down-flowing coolant from the 16 outer (second pass) elements into the lower plenum region where final distribution of the flow takes place. The guide tubes also serve to prevent cross-flow and the accompanying lateral thrust against the control rod extensions.

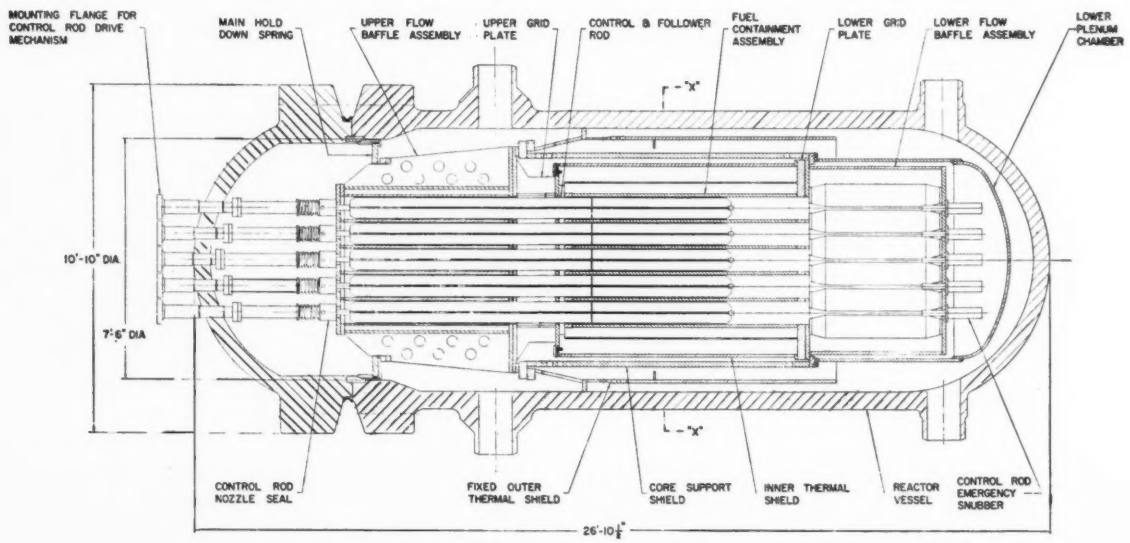


Fig. 1.—Section through the *Savannah* reactor. In the vessel the reactor is, of course, upright

From the lower plenum a minimum of 85* per cent. of the total primary coolant flows into the 16 inner guide tubes which serve as a hydraulic entrance section prior to the entry into the third pass fuel elements. Approximately five per cent. of the total coolant flow is orificed into the control rod channels; the remaining 10 per cent. has been allocated to miscellaneous leakage and the small quantity bled into the reflector region.

Complete Turnabout

Guide tubes above the core conduct the coolant streams directly to the upper plenum of the vessel and, at the same time prevent cross-flow and lateral thrust against the control rods in the "out" position. The coolant streams mix in the upper plenum, make a full 180° change of direction and flow downward to the exit nozzles.

The core and internals are held down against the upward thrust of the coolant by the upper baffle hold down spring. The downward force is transmitted to eight equally spaced vertical struts which bear on the upper grid plate, as shown in Fig. 1. The internals are designed to prevent motion of the core under the worst specified conditions of roll, pitch, and heave of the ship. The internals also are designed to prevent motion of the core in the event the ship should capsize and sink.

No Bulk Boiling

The core design is the result of an optimization of thermal, hydraulic, mechanical, nuclear and economic design considerations. The thermal design criteria are as follows:

1. No bulk boiling will be permitted in the core during steady-state operation.

2. The local heat flux at the outside surface of the cladding shall not exceed the design value of burnout heat flux, either during steady-state operation or during any transient operation, regardless of the duration of the transient.

3. Local values of the internal temperature of the oxide fuel shall not exceed the melting temperature of the fuel under the worst possible combination of manufacturing tolerances, neutron flux distribution, and fluid flow effects during steady-state or transient operations.

Preliminary nuclear parameter studies indicated that a metal-to-water ratio near unity is desirable. This is a compromise between a desire to have a large amount of resonance capture in U-238, which dictates a large M/W ratio, and a desire to reduce the uncertainties resulting from resonance fission. A metal-to-water ratio near unity is also necessary to keep the coolant flow area between fuel pins in a reasonable range. If too large a water fraction is used, the pumping power becomes excessive.

30,000 ft. of Fuel

It can be shown that for a given central fuel temperature the power output per unit length of fuel rod is approximately independent of rod diameter. Hence the requirement that the fuel melting temperature not be exceeded dictated that the total length of the fuel rods be approximately 30,000 ft. Another requirement which has had a strong influence on the final core arrangement was the requirement that the control rod pitch be kept to a minimum to achieve maximum reactivity control from the rods.

Advantages of Multi-Pass

A multi-pass arrangement was selected because of the advantages in thermal performance of this arrangement over a single pass core. Some of these advantages are:

(*a*) Improved utilization of the coolant by virtue of the fact that the fluid flows in succession through the regions of low, intermediate and high heat generation. In this design at least 85 per cent. of the fluid passes through the central 16 fuel elements. To approach the same result in a single pass system, one must resort to orificing of the individual fuel elements. The latter is not an entirely satisfactory approach because of the variation in power distribution over the core lifetime.

(*b*) For a specified operating pressure, the flow velocity over the fuel rod surface must exceed some minimum value to satisfy heat transfer requirements. As a result, the primary coolant flow rate for the multi-pass system is approximately one-half that of a single pass design. It can be shown that under the additional constraints imposed by economic piping design, the total plant pumping power is less for a multi-pass system than for a single pass core.

A Major Objection

The use of downflow in a fuel region has been considered a major objection to the use of a multi-pass core design. The possibility of flow reversal with resultant steam formation and burnout exists if high power density, large gradients in power density, and low pressure drop occur simultaneously. Analysis of this design shows that spontaneous flow reversal will not result even when only a single pump is running at half speed and a factor of two in power density exists between any two fuel elements in the second pass. This conclusion applies for the worst combination of pitch and roll of the ship. If all pumps fail the reactor is scrammed. During decay heat removal by emergency cooling, the heat generation rates are too low to cause burnout even if flow reversal should occur.

The thermal design parameters are summarized in Table I.

Table I

Design power	74 (t)MW
Flow rate	8.0×10^6 lb/hr
Operating pressure	1,750 lb/sq.in. abs.
Inlet temperature	494.8°F.
Temperature rise	26.4°F.
Average heat flux	57,100 B.t.u./hr-ft²
Pressure drop, nozzle to nozzle	24 lb/sq.in. abs.

The distinguishing feature of this core design is the reactivity lifetime of 600 full power days. In order to attain this long life, a large, low power density core is used. The initial consideration in designing such a core is the determination of the excess reactivity required and then provision for controlling it. The use of fertile material extends the core lifetime both by producing plutonium, to replace part of the U-235 that is consumed, and by allowing a larger excess fuel inventory for a given excess reactivity. The conversion ratio is 0.4. It can be shown that the use of stainless steel in the core does not reduce the core life

*The 85 per cent. figure was specified as a design requirement at the very beginning of the core design. Present indications are that more than 85 per cent. will be available to the third-pass elements.

appreciably. The reduction in conversion ratio is more than offset by the larger fuel inventory which can be held down by the control system.

For the bulk of the physics calculations a modified two group diffusion theory model was used. Effects of resonance capture and fission are included as a resonance multiplication factor. Calculations were made using a 40 group spectral programme to obtain values of p_{25}, p_{28} and p_{total} to give the proper neutron balance in the resonance energy region. These constants were then used in the two-group criticality and lifetime studies.

A value of the resonance integral for U-238 in UO_2 rod, light water lattices was derived from the analysis of a series of critical experiments. These experiments bracket the values of the important parameters of surface-to-mass ratio and scattering per U-238 atom which occur in this core. A value of 22 b. for the resonance integral of U-238 is used. Resonance integrals of 2.5 b. for stainless steel and 2 b. for Zircaloy-2 were also used.

4 per cent. Enrichment

The enrichment required to provide a 600 day core life at 74 MW is approximately 4.0 per cent., which corresponds to an initial U-235 inventory of 330 kg. The cold, clean core should have an excess reactivity of 15.5 per cent. $\triangle k_{eff}$. The reactivity requirements are as follows:

	Per cent. $\triangle k_{eff}$
Temperature coefficient 68°F.-508°F. (including power coefficient) ..	6.5
Xenon and Samarium poisoning	2.8
Lifetime reactivity ..	4.2
Manufacturing tolerances	2.0
Total	15.5

The total reactivity that must be controlled is 18.5 per cent. $\triangle k_{eff}$ assuming that the cold, clean reactor must be 3 per cent. $\triangle k_{eff}$ subcritical when loaded. Since the control rods are estimated to be worth only 15 per cent. $\pm$ 1 per cent. $\triangle k_{eff}$, it is necessary to use approximately 3.5 per cent. $\triangle k_{eff}$ in burnable poison. The reactivity required to override transient Xe-135 is only 0.15 per cent. $\triangle k_{eff}$. This small value is due to the low thermal neutron flux (8×10^{12} n/cm²/sec) and large absorption cross-section in the core.

Reactivity Calculations

The reactivity hold-down available in the control rods has been estimated in several ways:—

(*a*) The Hurwitz-Roe absorption area concept was used but modified using P-3 transport theory to calculate the number of neutrons captured per cm² of rod.

(*b*) A cell calculation was performed in which the infinite multiplication constant of an array of fuel elements and control rods was first calculated. The amount of distributed absorber required to reduce the infinite multiplication of the lattice without control rods to that of the control rod-fuel element array was then determined and inserted in a multi-region criticality calculation of the actual core.

(*c*) Extrapolations from critical experiment data were made weighting the worth of each control rod by the product of the thermal flux and adjoint function, making corrections for the diffusion length and core diameter.

All three methods gave the result that rods would be worth 12.5 per cent. $\pm$ 1 per cent. $\triangle k_{eff}$ if they were black to thermal neutron but absorbed no epithermal neutrons. Experimental comparison of cadmium with hafnium and with a cadmium-indium-silver alloy indicate that a 20 per cent. increase in rod worth, due to resonance capture of neutrons, can be expected. This should increase the total rod worth to 15 per cent. $\pm$ 1 per cent. $\triangle k_{eff}$.

γ—δ—Φ Programme

The calculation of the core lifetime to be expected for a given initial enrichment was made using the Gamma-Delta-Phi programme developed by The Babcock & Wilcox Co. This programme utilizes a multi-region, modified two-group criticality calculation coupled with the U-238 isotope buildup equations. The programme is capable of handling non-uniform burnout in up to nine regions in slab, cylindrical or spherical geometry.

At each time step, the thermal and fast neutron flux profiles are computed. The average fluxes in each region are then computed and used to determine the change in the

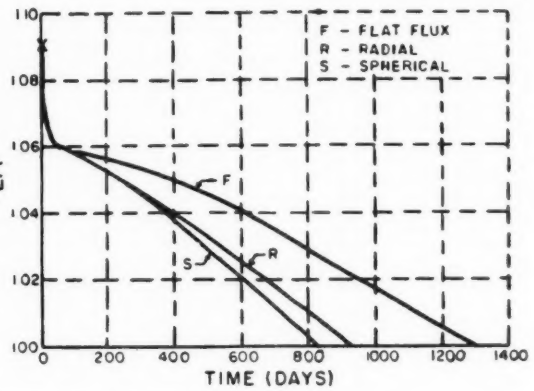


Fig. 2—Graph showing reactivity in relation to operating time, at a power of 74 MW

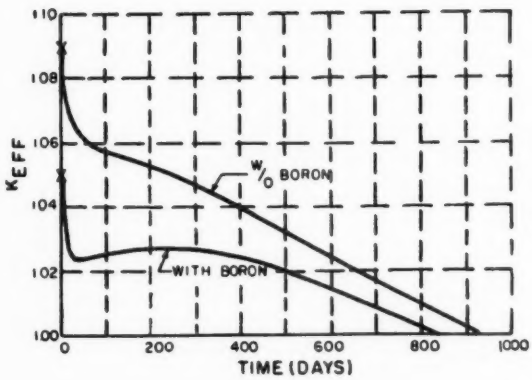


Fig. 3.—Reactivity in relation to operating time at 74 MW with burnable poison (B^{10}) and non-uniform radial burnout

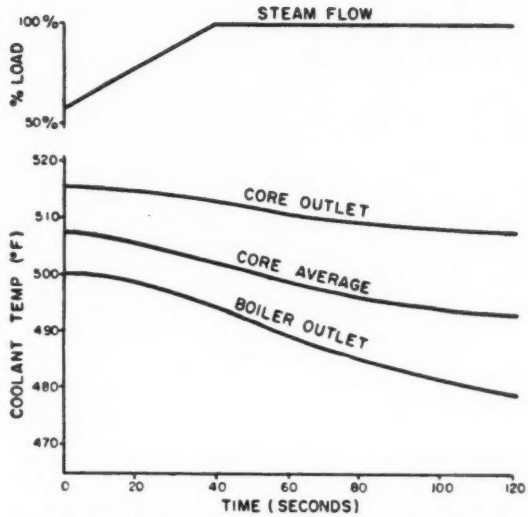


Fig. 4.—System response to load change—no control

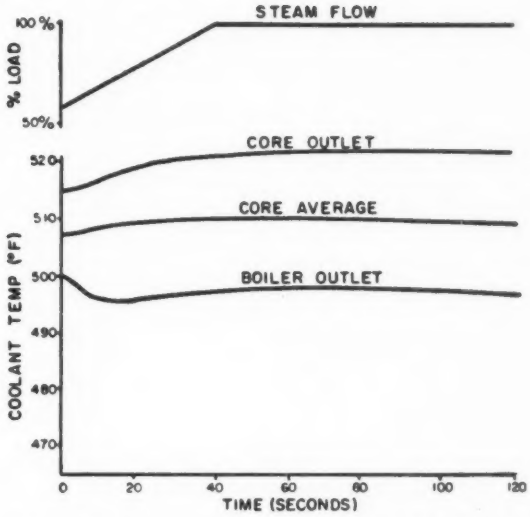


Fig. 5.—System response to load change—control by shim rod movement

concentration of U-235, U-238, Pu-239, Pu-240, Pu-241, Xe-135, Sm-149, two groups of fission products, and one burnable poison. The calculation includes resonance capture in all uranium and plutonium isotopes and allows for resonance capture in one structural material. A comparison of lifetime calculations with 4.0 per cent. U-235 enrichment assuming a flat flux and a calculation taking into account radial and axial non-uniform burnout are shown in Fig. 2. A non-uniform burnout calculation in spherical geometry is also shown as a representation of three dimensional burnout. The quantity $k_{eff}-1$ derived from these curves is the amount of excess reactivity which must be held down by the rods at any point in the core lifetime.

Control Requirements

The behaviour of excess reactivity as a function of core operating time with 4 per cent. $\triangle k_{eff}$ held down by boron in the fuel is shown in Fig. 3. Because of the errors inherent in calculating the reactivity behaviour with burnable poison the amount of excess reactivity held down by boron must be limited to 4.0 per cent. $\triangle k_{eff}$. Sufficient control must be available in the rods to keep the reactor critical as the Xe-135 and Sm-149 poisoning reaches equilibrium. Sufficient control in rods must also be provided to override a rise in reactivity which may result if the boron burns out more rapidly than the fuel. It is apparent from Figs. 2 and 3 that a manufacturing error of $\pm$ 1 per cent. in the initial reactivity can be allowed and a 600-day core life obtained.

Doppler Broadening Effect

The temperature coefficient of reactivity was obtained by differentiating the critical equation for an equivalent bare cylinder. Coefficients associated with water and fuel temperatures are evaluated independently. At 508°F. the temperature coefficient of reactivity associated with water temperature is -2.3×10^{-4}/°F., while the fuel temperature coefficient is between -1.5×10^{-5}/°F. and -3.5×10^{-5}/°F.

The existence of a large negative fuel temperature coefficient, due primarily to Doppler broadening of the U-238 absorption resonances, creates a unique control problem in this reactor. Weighting the fuel temperature by its spatial distribution according to first order perturbation theory, the proper temperature to be used in calculating the Doppler broadening effect is:

$$\triangle \overline{T}_{\text{Doppler}} = \frac{\int_c \triangle T_{\text{Fuel}}(\eta,Z) \cdot \phi(\eta,Z) \cdot \phi^*(\eta,Z) \cdot dv}{\int_c \phi(\eta,Z) \cdot \phi^*(\eta,Z) \cdot dv}$$

The effective Doppler coefficient is 1.8 times as large as would be calculated from the average fuel temperature in the core.

An electrical analogue simulation of the entire reactor plant has been in progress at Battelle Memorial Institute. Weighted temperature coefficients coupled to the mean temperature of each core pass were calculated taking into account spatial temperature distributions and neutron importance functions. It was found that the large negative fuel temperature coefficient, which is reflected as a negative power coefficient, would override the water temperature coefficient when the plant load was changed. The behaviour of the system to a load change of 25 MW in 40 sec with no motion of control rods is shown in Fig. 4.

Purpose of Shim Rods

In order to maintain a constant reactor water temperature it is necessary to move shim rods to counterbalance the Doppler coefficient. Using a temperature signal from the boiler outlet and error signal obtained by comparing neutron flux and steam flow it is possible to maintain a relatively constant mean reactor temperature as shown in Fig. 5.

One of the properties of a reactor core with a large $k\infty$ and a small migration length is that large peaking factors can result if the control rods are improperly positioned. If two or three adjacent control rods are

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CERAMIC COATINGS

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coated and uncoated specimens is much greater.

Although none of the coatings so far evaluated by the microscopic method greatly reduced the depth of uniform oxidation that occurs beneath the coating, the depth of stringer penetration was reduced from 1.55 mils on a bare specimen to a minimum of 0.65 mils under coating N-108, and the number of stringers per inch was reduced from 228 to 20.

A series of thermal shock resistance tests was performed on coated specimens of various alloys as well. The coated specimens were heated in a furnace and then quenched by total immersion in water at room temperature. All withstood quenching from 1100°F., and the best did not fail when quenched repeatedly from 2000°F. This thermal shock treatment is much more severe than the coatings would normally be expected to encounter in service.

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BOOK REVIEW

Lectures on Nuclear Theory, by L. Landau and Ya. Smorodinsky. (Translated from the Russian). Revised edition. Plenum Press, Inc., New York, 1959, (Chapman and Hall, Ltd., London). Size 6 in. × 9 in. × 108 pp. Price 45s.

This book was originally published in English translation in 1958 by Consultants Bureau Inc., at $15.00 in paper backed form. It is based on a series of ten lectures given in Moscow in 1954, intended for experimental nuclear physicists, but they will also be useful to physicists working in other fields who wish to understand the basic problems of nuclear physics. They will be especially valuable to physics research students. When the lectures were given there was no satisfactory theory of nuclear forces. This is still the case, and is likely to remain so for a long time. Although some new ideas have come forward in the interval, and some new discoveries have been made together with a wealth of new experimental data, the treatment of the particular topics presented remains essentially valid. As might be expected of such distinguished authors the presentation is most lucid and stimulating. The anonymous translator has served them well. There has been no attempt at an exhaustive or even a rigorous survey, but some of the more important ideas and principles of nuclear physics are discussed on the basis of theoretical interpretation of the experimental results available at the time, with the help of general quantum mechanical relations. The first three lectures are concerned with nuclear forces, illustrated by discussion of the scattering of neutrons by protons and of protons by protons at low and high energies. Such traps for the unwary as the fact that the interaction energy can greatly exceed the binding energy are carefully and clearly explained, and the importance (and difficulty) of phase shift analysis in scattering are well brought out. The next three lectures deal with nuclear structure, one outlining the independent particle model which is based on an analogy with the shell structure of atoms, one analysing the magnetic moments of light nuclei, in terms of this model, and the other discussing the structure of heavy nuclei, including non-spherical nuclei (on the basis of the Bohr-Mottelson model). At this point several relevant formulae are described in an Appendix (e.g., the quadrupole moment of a uniformly charged rotating ellipsoid). The seventh and eight lectures describe nuclear reactions according to the statistical model and the optical model of nuclei, the latter including also a brief discussion of the deuteron stripping process. π-mesons, and their interactions with neutrons and protons, are treated in the last two lectures. Antiparticles are mentioned in connection with charge conjugation. "Strange particles" are not discussed; although they were discovered before the lectures were given, most of present knowledge about them has been gained since that time. Similarly, beta-decay is not very much discussed and so the later discovery of non-conversation of parity in weak interactions hardly affects the topics presented. The lectures are not bogged down in masses of experimental results and mathematical detail, but stress basic physical ideas and the essential features of the knowledge gained from experiments. From this review it will be apparent that a good basic knowledge of physics and some familiarity with quantum mechanics are required to appreciate this excellent little book. There is no bibliography.

T. G. Pickavance, BSc, PhD
NIRNS, Harwell

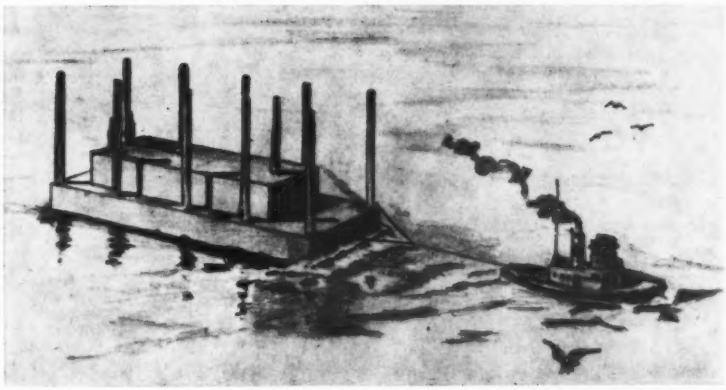
SAVANNAH
Reactor Physics

(*Continued from page 453*)

removed from the core while the rest of the core is held down by other rods it would be possible to localize the power generation to a small volume of the core. Since the thermal design of this reactor is somewhat conservative, an overall power peaking factor of 5 can be tolerated before the thermal design criteria are exceeded. Estimated peaking factor around the control rod channels is 1.3 while the factor for axial distribution is 1.5. This allows a radial peaking factor of 2.6.

A full-scale critical experiment has been constructed at the Babcock & Wilcox Critical Experiment Laboratory in which experiments are being carried out to verify the calculations discussed in this article and determine several important parameters which are difficult to calculate with any accuracy. Problems in reactor physics which can most easily be answered by measurements in a critical experiment are (1) thermal utilization in a close-packed, heavily loaded rod lattice; (2) the effectiveness of control rod in a lattice of highly absorbent fuel pins; (3) competition between U-235, U-238 and structural materials for neutrons in the resonance regions; (4) power distribution with various control rod patterns.

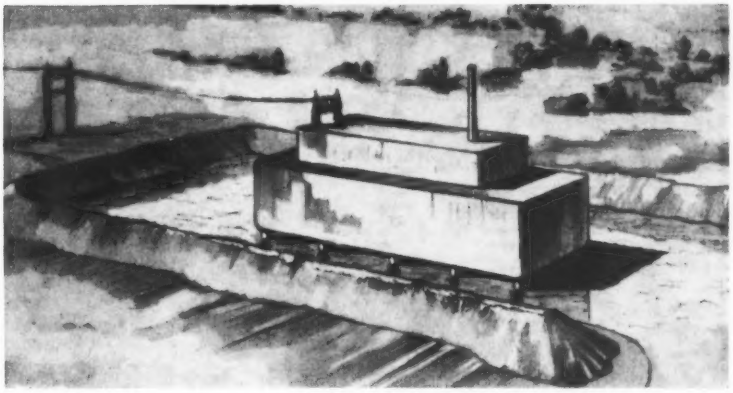
In the economics of present day pressurized water power reactors, the core fabrication cost is a more important factor than fuel inventory charges. The design philosophy of the *Savannah* ship reactor has been to minimize core fabrication cost by providing liberal manufacturing tolerances and a long core life. Fringe benefits of this philosophy are liberal thermal and nuclear design requirements and large margins of safety against operational mishap.



Delivery by Sea

NOVEL PORTABLE N-PLANT

For the installation of power plant in remote areas having access to navigable waters, the H. K. Ferguson Co., of Cleveland, Ohio, have designed a plant which can be towed as a barge (above) to its site, grounded and then jacked into position (right). Thule, Guam, Alaska, Antarctica, the seaport and river towns of Central and South America, Africa and Asia are potential locations envisaged in this project.



THE H. K. Ferguson sea transportable nuclear power plant consists of a complete generating unit mounted in an ocean-going barge which is fitted with hydraulic jacking caissons for supporting the entire unit at the selected site. Any one of three reactor systems can be used in the plant—the organic moderated reactor system, as designed by Atomics International, a Division of North American Aviation Inc., the pressurized water reactor system designed by Babcock and Wilcox, and the boiling water reactor system as designed by Nuclear Products-Erco Division of ACF Industries. The plant is designed for a net electrical output of between 10 MW and 40 MW.

Conventional Barge

The barge in which the plant is mounted is 150 ft long × 70 ft beam × 20 ft draft with full ballast (15 ft draft without ballast) and with a 13 ft freeboard. It is of all steel, double hull construction and the hydraulically jacked caissons mounted along each side of the vessel are so arranged that the load of the barge and its contents are equally distributed between them.

The space between the caissons is used for ballast tanks.

The barge is divided into shielded and unshielded compartments; the equipment which is a potential source of radiation being located in the shielded parts.

The barge will be fabricated, complete with bulkheads and shielding, in a conventional manner. After launching it will be fitted with the mechanical equipment in a regular fitting basin and the entire system will then be checked and tested under operating conditions.

Towing to the site will be carried out with conventional towing equipment. A channel will be dredged at the site into which the barge will be towed and then jacked into position by means of the caissons. If desired, the channel may be filled in to provide additional shielding and easy access to the plant.

If the station is required for only temporary or emergency purposes the barge could be moored alongside a dock or the shore and jacked up only enough to be unaffected by tide and wave action.

Capital costs of plant according to output are estimated to run from $5m. to $12m. Delivery of the plant can be obtained within 12 months of the placing of a firm order, so that construction and testing within an 18 month period is possible.

Soviet Particles

A CYCLIC accelerator with spatial magnetic field variation has been developed at the nuclear problems laboratory of the Joint Nuclear Research Institute in Dubna, near Moscow. This is a new type of charged particles accelerator. Development work on such accelerators is under way in a number of countries, but nowhere in the world is there an accelerator of a similar type in actual operation. The new type of accelerator, designed and built under the supervision of Soviet physicists Benedikt Dzhelepov, Vitaly Dmitrievsky and Boris Zamolodchikov, differs radically from existing machines. Unlike these, its variable magnetic field varies in space, so that the field's lines of maximum tension fall into an Archimedes spiral. Very soon this type of accelerator will produce accelerated particle beams thousands and even scores of thousands of times more intense than those obtained in the high energy accelerators known up to now.

INSULATION

of a Nuclear Power Station

EXPERIENCE AT BERKELEY

SIZE is the factor which, from the lagger's point of view, distinguishes Berkeley from a "conventional" power station. The vastness of the two reactors, pressure vessels each 80 ft high and 50 ft in diameter made of 3 in. thick welded steel, means that, even though the operating temperature is only 650°F., expansion is exceptional.

Meeting the problems presented by the expected expansion of each reactor pressure vessel has been the special concern of the Cape Asbestos Co., Ltd., who have been entrusted by AEI-John Thompson Nuclear Energy Co., with the insulation of the entire station.

Site Stress Relieving

Each of the two pressure vessels at Berkeley has a cylindrical body with domed ends. From the top of the side come the eight outlet gas ducts each 5 ft in diameter; from the lower dome come the eight inlet ducts.

Each pressure vessel is being insulated with 7 in. thick "Caposite" amosite asbestos moulded blocks—two 3½ in. thick blocks fixed to lagging pins welded to the surface of the pressure vessel and laced on with wire.

Stress relieving has been done on site, since its size only allows it to be assembled once and in position. The insulation fitted to the pressure vessel, therefore was designed for the stress relieving temperature and though this meant a thickness greater than required by the operating temperature, no part of the lagging was removed except for weld inspection since this would have involved unnecessary time and expense.

Metal Work Problem

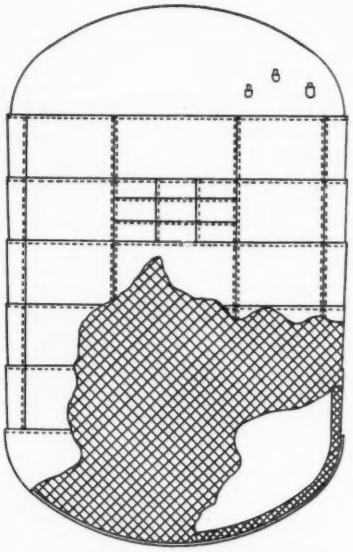
Methods used for lagging the first pressure vessel are little different from those used in a conventional power station. To design and fabricate satisfactory metal work to cover the insulation however was another matter and this has confronted Cape Asbestos Insulation Division with many problems. Drawings have had to be made to show every detail of fitting, and the whole outer aluminium shell for the pressure vessel—only No. 1 is so far ready—has been fabricated piece by piece in the metal fabrication department at the Cape Asbestos Barking works.

To allow for an expansion of 6 in. from cold to full operation the aluminium has been mounted in panels of nine or six sheets with only the centre sheet anchored to the surface of the pressure vessel. Labyrinth joints allow horizontal movement between panels which can slide in and out without exposing the surface of the Caposite. Straightforward overlapping downward joints between sheets prevent exposure due to vertical movement. In the side of the insulation and its metal cleading holes have had to be cut to take the tubes and probes entering the pressure vessel wall at right-angles.

Complications

There is no metallic connection from the steel surface to the pressure vessel to the aluminium facing via the studs which secure the insulation, since washers of Asbestolux asbestos insulation board separate the aluminium from the top of the stud.

The metal work required to cover the tubes and rods which issue from the top of the dome—193 of them—meet the dome at a variety of angles, is even more complicated. Barking drawing office had to devise metal coverings in 28 different angles and each of the 193 angle pieces was individually made in the metal shop. Moreover there were two diameters—1 ft bore charge tubes and 9 in. bore control rod standpipes. The Caposite insulation beneath the cleading on the dome is hand cut to take the various holes for the rods. The



Drawing of a Berkeley pressure vessel, showing arrangement of asbestos lagging and wire work covering

insulation on the tubes and rods is 3½ in. Rocksil with Caposite spacers, and extends up to the roof. The lower dome which has no tubes or rods entering it is insulated with Caposite blocks finished with aluminium.

Dealing With Ducting

Each pressure vessel has a run of gas ducting 5 ft in diameter to and from each of the eight boilers it serves—big size ducts carrying large quantities of low pressure gas. None of these runs is identical. The upper ducting from the top dome to the boilers is being insulated with 3 in. thick Rocksil rock wool mattress and the lower ducting with 2 in. thick Rocksil mattress. These mattresses are 1½ ft to 2 ft in length and wired on.

Insulation of the valves and of the stainless steel "bellows" which occur in numerous places along each run to allow movement of the pipe through heating, presented special problems.

The insulation of the valves which control the 500°F. gas flow is 8 in. thick.

The anchor plates of the "bellows" must expand at the same time as the ridges of the bellows and the temperature inside the "box" must be constant. To meet these requirements double insulation is being fitted—Caposite blocks inside trays directly round the undulating surface

(*Continued opposite*)

The John Jay Hopkins Laboratory

N-Centre Opened

THE John Jay Hopkins Laboratory for Pure and Applied Science at San Diego, California, which was recently opened by renowned physicist Niels Bohr, is focal point of the activities of the General Atomic Division of General Dynamics Corporation. Work under way there includes projects on the development of high temperature gas-cooled power reactors for both land and marine applications, research in controlled thermo-nuclear reactions, a feasibility study of nuclear space ship propulsion, and the development of reactors for research, training, isotope production and for medical and industrial uses.

The laboratory, which is named after the founder and chairman of General Dynamics, cost $10m. It comprises about 100 different laboratories and buildings which cover a floor area of nearly 300,000 sq.ft. Staff numbers about 700.

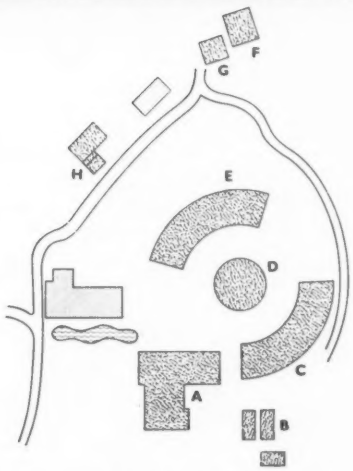
TRIGA, the prototype research and training reactor designed by General Atomic, is housed at the laboratory, in a building at the north end of the site (marked G on the plan). This reactor, designed to have a steady power output of 100 kW, was "flashed" at the laboratory opening ceremony to a peak power of 1,500,000 kW.

For Radiation Studies

Another large piece of equipment is a 30 MeV linear accelerator (building marked H). This is used for studying radiation damage in gases and solids, measuring neutron spectra and neutron capture cross-sections, and studying the preservation of food by irradiation.

Centrepiece of the laboratory is a circular building (D) housing the library and information services. The library contains some 20,000 books, journals and reports; facilities are provided for the editing and publishing of technical papers.

Encircling the library are two arc-shaped buildings. One of these is the metallurgy and experimental physics building (C) and houses equipment for research into many areas of metallurgy and ceramics, including work on fuel developments of the 40 MW gas-cooled reactor station the company is to build for the Philadelphia Electric Co. at Peach Bottom, Pa., and a wide range of work on thermoelectric apparatus, semiconductor devices, atomic particle physics, changes in the properties of materials due to radioactivity, and the behaviour of matter at extremely low temperatures. An electronics group works on the development of electronics and control circuits.



Photograph and drawing to show layout of the laboratory buildings and facilities. Key : A—Experimental Building ; B—Fusion Research Centre ; C—Metallurgy and Experimental Physics Building; D—Library-Technical Information Centre ; E—Chemistry Building ; F—Radiochemical Facility and Hot Cells; G—TRIGA Reactor Building; and H—Linear Accelerator Building

The other arc-shaped building (E) is for research into nuclear chemistry and includes facilities for the determination of the behaviour of reactor materials at high temperatures, studies of the means of trapping power reactor fission products, and the development of advanced methods of producing radioisotopes.

Other buildings include a fusion research centre (B), an experimental building (A) where novel fuel elements are developed and experiments requiring large rigs are carried out, and a radiochemical facility and hot cells (F).

INSULATION

(*Continued from opposite*)

of the bellows and Rocksil mattress round the vanes of the box in which it is housed. The whole is then covered with aluminium, with a swaged joint to allow for movement from expansion.

Insulation of the boilers at Berkeley is being carried out in 3 in. thick Caposite blocks with expansion joints every 10 ft. Stress relieving is done in the workshops at Berkeley where the segments are welded together before erection, and the insulation is a set of Rocksil mattresses which are fitted to each boiler in turn and then removed to serve the next vessel to be stress relieved.

HYDROCARBONS

in Power Reactor Plants

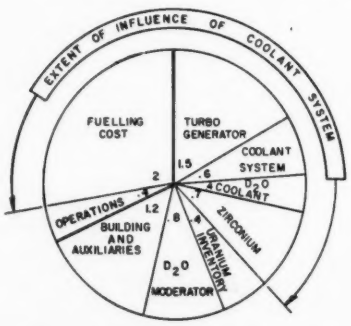
II—Canada's Organic Cooled Reactor Project

THE decision of Atomic Energy of Canada Ltd., to sponsor the design and development of a reactor which uses an organic liquid as a coolant stems from the success achieved with the Organic Moderated Reactor Experiment at Idaho Falls (described in NUCLEAR ENERGY ENGINEER, August, 1959). In this a hydrocarbon is used as both coolant and moderator and the results obtained from operation of the reactor unquestionably confirm its practicability.

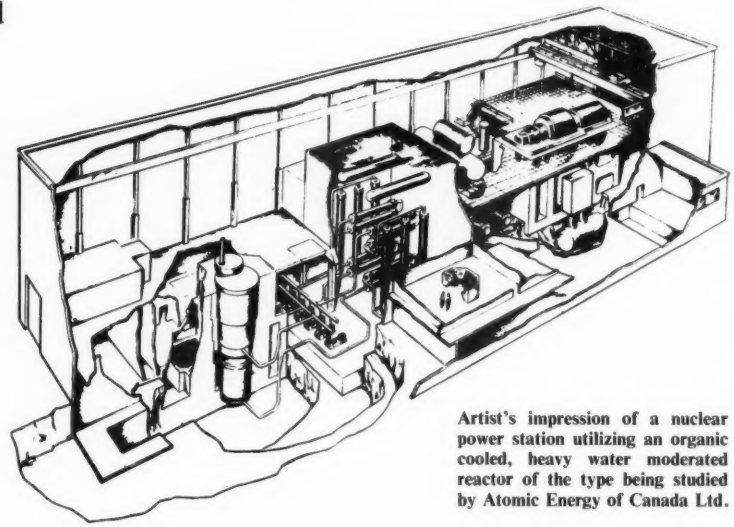
Unlike OMRE, the Canadian reactor will be designed to use an organic liquid as coolant only; the moderator will be heavy water. The use of a hydrocarbon as moderator would entail the use of enriched uranium as fuel; not unnaturally the Canadians are aiming at developing reactor systems which use natural uranium, supplies of which are plentiful in their country.

Costs Cut

Reactors developed in Canada to date all use heavy water as coolant. By using a hydrocarbon costs will be greatly reduced. The price of 1 lb of hydrocarbon suitable as a reactor coolant is about 40 cents: the price of a pound of heavy water is $28. An organic cooled reactor might not only prove economic for power stations in general but also be particularly attractive in small and medium sized stations for installation in remote areas, including some Arctic centres.



Influence of coolant system on power cost for typical heavy water reactor



Artist's impression of a nuclear power station utilizing an organic cooled, heavy water moderated reactor of the type being studied by Atomic Energy of Canada Ltd.

The Canadian organic reactor, to be known as OCDRE (Organic Cooled, Deuterium Moderated Reactor Experiment), is to be designed and developed by the Canadian General Electric Co. They have been studying this particular reactor concept for some time and at the International Conference on the Peaceful Uses of Atomic Energy last year presented a description of a preliminary design. In the meantime experiments to test some of the features of an organic cooling system have been conducted at Chalk River, headquarters and research centre of the Atomic Energy of Canada Ltd.

Vertical 150 MW Unit

The reactor described at Geneva was for a 150 MW power station. The plant consists of a vertical reactor designed for refuelling while in operation. Fuel is natural uranium and the coolant a mixture of terphenyl isomers. This mixture is circulated through two independent external heat-exchanger loops, each containing a steam generator in which steam is generated for a regenerative single-pressure turbine cycle.

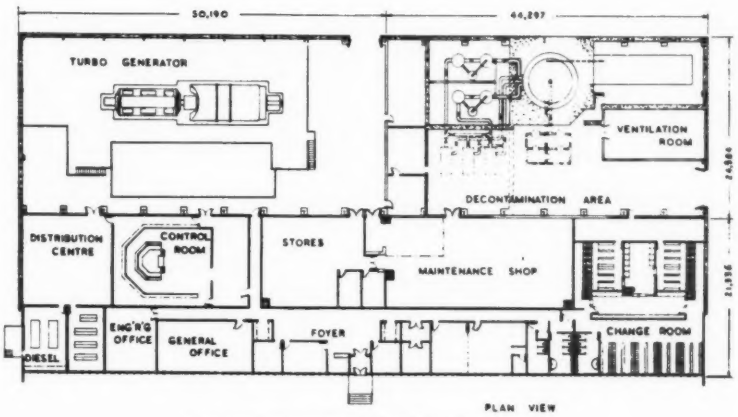
Control and shut down of the reactor is achieved either by variation of moderator level and "dump" in a manner similar to that used in NPD-2[1] or by the injection of poison into the heavy-water moderator.

Removing Tars

A coolant-purification system is provided in which the heavy radiolytic and pyrolytic tars produced during operation may be removed by distillation at reduced pressure. The extent of the purification will be adjusted to maintain the desired heat-transfer characteristics of the coolant material and it is expected that a build-up to 20 per cent.-30 per cent. tars in the coolant system will be permitted.

The necessary moderator cooling and purification circuits will be provided and will be generally similar to those for other heavy-water-moderated reactors.

The special safety provisions for this reactor are under consideration. The present design involves the elimination of stored energy which



Plan view of proposed 150 MW OCDR station

following equipment failure or mal-operation, might otherwise result in the vaporization of some portion of the contents of the reactor system with resultant dispersion of active material.

The core consists of an aluminium moderator tank about 15.5 ft in diameter and 13.7 ft in height, containing heavy water. Two fuel rods stand end-on-end within each of the aluminium-alloy coolant tubes which pass through the vertical channels constructed in the moderator tank. These channels or calandria tubes are in integral part of the moderator tank and are spaced on a 9.65 in. triangular lattice. The calandria tubes prevent the moderator contacting the coolant tubes, and permit a 0.22 in. insulation space filled with carbon dioxide gas to be maintained between the hot coolant system and the relatively cold moderator.

CO_2 Cools Moderator

The moderator tank is surrounded by a radial 2 ft thick graphite reflector which is cooled by forced circulation of carbon dioxide.

Organic coolant material is supplied from a lower header to the base of all the coolant tubes and flows upward through the fuel, finally discharging into a large upper header pool. The hot coolant material is drawn off from the side of this pool and circulated through the steam generators, finally returning to the lower header again.

The large carbon-steel upper header pool which is a major feature of this design, serves a multiple purpose as:—

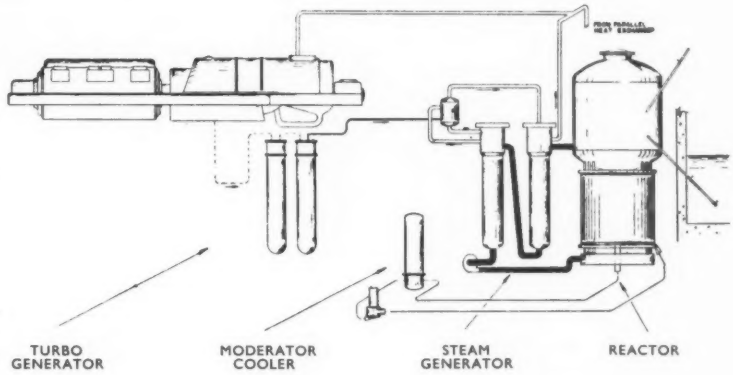
(*a*) coolant storage immediately above the reactor core;

(*b*) upper radiation shield for reactor; and

(*c*) shielding and cooling and temporary storage for fuel during handling operations prior to transfer to the storage bay.

Work of Baffle

The mixing of hot coolant material within the upper header pool is restricted by an internal baffle, thereby minimizing the stored energy



Schematic arrangement of plant for 150 MW station

Design Data for Proposed 150 MW Station

General

Net electrical output	150 MW
Net station efficiency	32 per cent.
Plant availability—in excess of 90 per cent. when refuelling while in operation.	

Reactor

Core diameter	15.5 ft
Core height	13.7 ft
Number of fuel sites	337
Lattice pitch (triangular)	9.65 in.
Side reflector thickness	2 ft
Heavy-water charge in core	70,000 kg
Fuel charge in core	37,000 kg UO_2

Coolant System

Temperature at inlet to core	302°C.
Temperature at exit from core	427°C.
Total mass flow in system	9.55×10^6 lb/hr
Maximum coolant velocity in core	28.2 ft/sec
Radiolytic and pyrolytic damage rate	88 lb/hr
Maximum pressure drop in core	95 lb/sq.in.

Nuclear Data

Assumed mean burnup of discharged fuel—6,000 MWD/tonneU.	
Mean thermal-neutron flux in fuel at centre of core—1.5×10^{14} n/cm² sec	

Fuel Rods

Active length of fuel rods	6.7 ft
Active fuel cross-section	4.16 sq.in.
Sheath thickness	0.030 in.
Mean width of coolant channels	0.080 in.
Maximum sheath temperature	445°C.
Maximum surface heat flux	450,000 B.t.u./sq.ft/hr

Steam Turbine

Steam conditions at turbine stop valve	1,550 lb/sq.in. 416°C.
Condenser vacuum	1 in. Hg.
Net cycle heat rate with 0 per cent. make-up	9,700 kilojoules/kWh
Regenerative feed heat temperature	232°C.

in the coolant system and eliminating major temperature differentials in the walls of the main vessel. This baffle arrangement is not subject to any appreciable pressure differentials as it operates at the same pressure as the upper header pool (2.8 at.).

Fuel changing may be carried out under operation of the reactor at full power by a machine which operates on a rotating platform, within the upper header pool but above the coolant liquid level. The machine is therefore outside the reactor shielding and readily accessible for removal and replacement with a stand-by machine, through the port in the upper header.

Fuel Washing

The pressure lock in the fuel-discharge chute is the portion of the fuel-discharge system where the change from an organic to a water system is accomplished and it contains provision for washing the fuel with steam prior to discharge to the storage bay. The wash liquid is sent to a recovery system or to disposal.

The heavy-water-moderator system provides for injection of a liquid poison at any time when a major emergency requires immediate shutting down of the reactor. There would be provision for the removal of the poison by ion exchange and the system could also be used to accommodate any long-term reactivity changes of the core.

Some " booster rods " containing enriched uranium may be provided similar to those in NPD-2 in order to permit the override of poison built up during a temporary shut down.

The moderator level may be varied to provide the normal operational control of the reactor. This method of control may also be employed for emergency shut down by a means similar to the " dump " principle used in NPD-2 and this is now under development.

Moderator cooling is accomplished by circulation through an external heat exchanger, thereby maintaining a mean temperature of approximately 60°C.

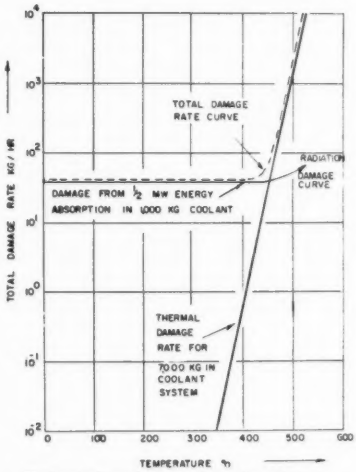
Mixture Chosen

A mixture of 20 per cent. to 30 per cent. ortho- and 80 per cent. to 70 per cent. meta-terphenyls has been tentatively selected as the most suitable coolant material on which to base design; however, it is considered that appreciable scope exists for later modification of the coolant make-up material if desirable, either from considerations of cost or radiation stability.

Tar Percentage

It is proposed to operate the system with a content of up to 30 per cent. pyrolytic and radiolytic tar, and to control this content by vacuum distillation of a side-stream flow.

A maximum bulk-coolant temperature of 427°C. at exit from the core is proposed; this temperature was selected from consideration of the influence of temperature on the absolute rate of radiolytic damage as found by T. H. Bates *et al*[2], and on the relative rate of pyrolytic damage for



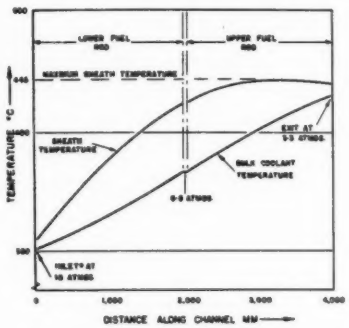
Estimated variation of coolant-damage rate with temperature for 150 MW reactor

this particular reactor. At temperatures exceeding approximately 450°C. the total pyrolytic damage starts to predominate in this reactor system; also, this temperature is approaching the point beyond which limitations on structural materials become a major factor.

The maximum surface heat flux in the coolant channels is approximately 450,000 B.t.u./sq.ft/hr and, assuming no surface on nucleate boiling to occur, the temperature distribution in the centre channel is 400°C.

The vapour pressure of the coolant material at 427°C. is approximately 2.3 at. It is proposed to use up-flow of coolant through the core in order to minimize the pressure in the upper header pool which will operate with 2.8 at. of gas pressurization.

No form of trace heating is considered necessary for the greater part of the organic-coolant circuit as the coolant material becomes liquid at room temperature after prolonged irradiation. At reactor start-up, prior to the accumulation of products of radiation damage, a charge of low-melting coolant material such as propylated terphenyl isomers may be used; this material would gradually be replaced by make-up with



Temperature distribution in coolant channel

the standard coolant material as radiation damage proceeds during operation of the reactor.

It is proposed to use a low-carbon steel for construction of the entire out-of-pile coolant system and to use shaft-sealed pumps for coolant circulation.

Absolute leak-tightness of the organic-coolant system is not considered a prime requisite of the system in view of the low cost of the material and absence of serious hazards. It is considered that the moisture content of the coolant material should be maintained below 400 parts/million for considerations of both corrosion and vapour pressure. Minor leakage of water or steam into the coolant system in the steam generators is not considered critical and moisture removal both in the distillation column and from the cover gas will be employed to hold down the moisture content of the coolant material.

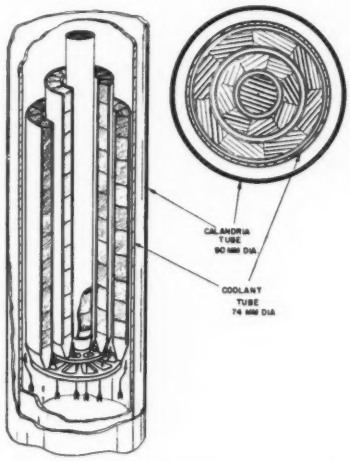
UO_2-Al Fuel Elements

Initially and because of its superior nuclear properties, consideration was given to the use of metal fuel in this type of reactor. However, the high radiation stability of ceramic fuel is very desirable and, with careful fuel-rod design, sufficient neutron economy

can be achieved using an aluminium-clad uranium oxide fuel to permit irradiations in excess of 5,000 MWD/tonne.

The proposed fuel rod has been designed to minimize the cross section of neutron-absorbing coolant whilst leaving sufficient spacing between adjacent fuel elements to ensure that local contact does not occur as a result of distortion under irradiation.

The concentric annular elements are clad with extruded and drawn tubes of sintered aluminium powder (SAP); this material is also proposed for the coolant tube because



Section and view of lower end of fuel rod

of its good strength at high temperature. A number of longitudinal fins may be formed on the sheath surface and would serve the dual purpose of providing extended heat-transfer surface, and providing spacing to prevent adjacent fuel elements touching.

Sintered Segments

The sheathing is joined to the aluminium-alloy and fittings by hot pressure welding or brazing in the absence of other suitable joining methods for SAP-type materials.

The fuel materials is prepared in the form of sintered uranium oxide segments which on assembly in the fuel rods make up complete annuli.

Thermal expansion of the fuel is unlikely to stress the sheath material if an initial clearance of 0.004 in. to 0.008 in. is provided between fuel and sheath. The fission-product gas evolved from the sintered oxide is estimated to generate only minor stresses in the sheathing and these will tend to be offset by the external pressure of the coolant on the annuli.

The main mechanical requirement for the sheathing is therefore sufficient strength to hold the oxide fuel in shape. It may be possible at a later date to use a high-strength magnesium alloy for this duty with a consequent gain in neutron economy; however, the present design is based on the use of aluminium materials. It might be noted, that with regard to corrosion of the sheathing materials, moisture content of the organic material becomes a far more critical consideration with magnesium than it is with aluminium sheathing.

Best Steam Conditions

The availability of a reactor coolant suitable for use at temperatures up to 425°C. would permit the generation of super-critical steam for turbine cycle. However, from consideration of overall cycle efficiency including feedwater pumping, it appears that, assuming a maximum steam temperature of 416°C., no advantage is gained by generating steam at pressure in excess of approximately 110 at. particularly if capital costs of equipment are taken into account.

An assessment of the most suitable steam conditions from the steam-turbine viewpoint indicate appreciable superheat to be desirable, in order to avoid undue moisture content in the steam at the exhaust end of the turbine and consequent erosion. In small units this problem may be avoided by the use of external moisture separators but in large units such separators are not considered desirable. Consideration of these aspects of the turbine has led to the recommendation of steam generation at 416°C. and 109 at. for the present reactor. The proposed turbo-generator is a 3,600 rev/min tandem compound triple-flow machine using six stages of regenerative feed heating and moisture extraction at the lower five extraction points where specially developed moisture-extraction buckets will be employed. The efficiency of the turbo-generator unit is estimated at 37.4 per cent., including feedwater pumping and assuming zero make-up and 1 in. Hg. vacuum.

The absence of any appreciable stored pressure energy in the primary coolant system of this reactor and the absence of chemical reactions with fuel, sheathing or heavy-water moderator considerably lessens the hazards of the reactor relative to many current power-reactor designs. The flammability of the material is comparable with that of lubricating oil and will require the installation of a foam fire-extinguisher systems as a safeguard for maintenance and necessary special operations.

Accident Prevention

The use of a hydrogenous coolant material in a heavy-water-moderated reactor can cause accidents involving loss of coolant resulting in increased reactivity of the core. Therefore, in the present design every effort has been made to counter this weakness by the provision of a large pool of relatively cold coolant material immediately above the core and by operation of the reactor with a minimum of 20°C. sub-cooling. The large pool of coolant material has sufficient capacity to ensure complete flooding of the reactor pit including the core if any failure to the coolant system within the pit area should occur.

The stored thermal energy of moderator and coolant within the reactor pit is such that, on mixing, neither material will vaporize. In consequence, even with the worst possible accident involving excessive power generation and some disruption of fuel rods and their surrounding coolant and calandria tubes, no vapour generation leading to serious dispersion of the released activity is expected.

The description of the reactor in this article is extracted from the paper, "A Heavy-Water-Moderated Power Reactor Employing an Organic Coolant" presented at the 2nd International Conference on the Peaceful Uses of Atomic Energy, Geneva, 1958, by M. J. McNelly, Civilian Atomic Power Department, Canadian General Electric Co.

References

[1]MACKAY, I. N., "The Canadian NPD-2 Nuclear Power Station," Conference Paper A/CONF. 15/P/209.

[2]BATES, T. H., *et al.*, "The Radiation and Thermal Stability of Some Potential Organic Coolant Moderators," Atomic Energy Research Est. Report AERE C/R 2121 (Harwell 1957).

'NUCLEARIST' writes . . .

WONDERFUL are the tricks the scientists get up to, in order to make things smaller and smaller. One would imagine that the Americans with their indefatigable tendency to see everything large, would be unable to visualize things on a small scale, and yet from the U.S.A. comes the latest development in miniaturization (what a horrible word!). The Radio Corporation of America has produced for use in the Army's communication systems the micro-module, which makes possible the size reduction of almost every electronic product. Devices in which micro-modules are used can be made about one-tenth the size of the present types, or even smaller. Small ceramic blocks, about 0.3 in. square, and consisting of thin wafers of conducting, semi-conducting, or insulating materials, are so small that 27 will fit into a cubic inch. Some wafers act as transistors, others as capacitors, others as crystals or valves. The completed packet of wafers is a whole electronic circuit, and can be driven by a battery the size of a shirt-button. These micro-modules will revolutionize electronics, and 500,000 electronic parts will be packed into an unbelievably small corner in a space vehicle. Logical developments will be radio sets and TV apparatus of pocket size, completely invisible hearing-aids, computers fitting into a cigar-box, and who knows what else?

* * *

Jupiter's moons have fascinated astronomers for many years, and to use space-rockets as probes in order to satisfy this curiosity is perfectly understandable. But, asks Dr. Chauncey Starr, general manager of Atomics International, in the address he made on his retirement from the presidency of the American Nuclear Society, may there not be other things of greater importance? Stressing the importance of maintaining a very high standard of intellectual integrity, Dr. Starr points out that there is pressure on members to emphasize viewpoints which benefit the vested interests of various groups. The professional body must be a forum for discussion and criticism free from bias created by special interests. It is difficult to prove that exploring Jupiter's moons is more important than finding a cure for cancer, and the means of pursuing scientific knowledge is not always justified if it results in the retardation of other endeavours of greater value to humanity.

Dr. Starr speaks boldly, for he is still associated with a large company whose very existence depends on continued progress in the fields of nuclear energy and space travel. It is to be hoped, however, that his words will not fall on stony ground. Even in Britain it is noteworthy that while rocketry and satellite research has been and will continue to be sponsored by government sources, cancer research is still very largely dependent upon voluntary aid. Dr. Starr is not alone in wondering if, in our prodigious thirst for technological knowledge, we may be neglecting the more humanitarian aspects of science.

* * *

Moving our accent to radioactive wastes, it is interesting to note that in the U.S.A., the AEC is putting further efforts into solving the big problems of disposal. Cameras are being built into probes which will be lowered to depths of 15 m into the sea-waters off the New England coast, in order to study the resistance of disposal vessels to erosion. Similar tests will be carried out at depths of 90 m about 50 miles off the harbour of Boston. In addition, there will be an examination of the fauna of the sea-waters, especially the crabs and molluscs which inhabit the sea-floor.

* * *

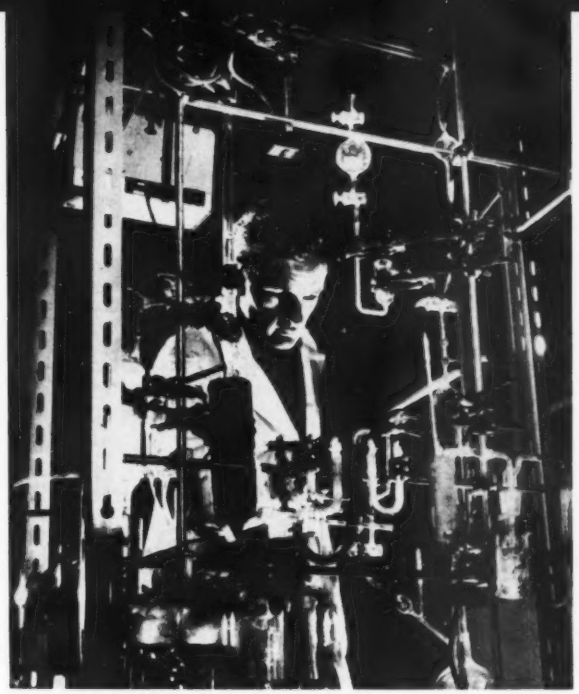
Kammerlingh Onnes was a name which fascinated me ever since, as a student, I learned of his masterly liquefaction of helium. I was particularly thrilled, then, on the occasion when I was allowed to make a complete tour of his famous low-temperature laboratory at Leiden, in Holland. This was a special honour, not only because I was the only visitor, but also because the director himself escorted me, chatting to me in excellent English. I recall how amused I was to hear that some of the complicated research equipment there had been made possible by the modest prices at which the British Government sold its surplus materials, which could be bought in bulk and used for many kinds of apparatus.

* * *

Low temperature research, of course, has been invaluable in the development of nuclear science. Particularly interesting, then, to me, was the news that the Kammerlingh Onnes gold medal has been presented this year to the research director of the Philips laboratories for " distinguished research work by the scientists of the Philips laboratories in the development of an economic and surprisingly simple machine for the cooling and liquefaction of air and other gases." This was the first time since its inception that the award had been made to a research team and not to an individual. The new machine uses a novel combination of air fractionating column and gas refrigeration, resulting in a simple, automatic plant which can produce one gallon of liquid nitrogen/hr from the atmosphere.

* * *

How long will it be before a nuclear rocket flies off from the earth, and will this event first take place from American soil? Such questions naturally spring to mind when we hear from U.S.A. sources that details have already been decided upon. It seems likely, if these can be believed, that the reactor will use as fuel pure U-235 moderated with graphite; the fission heat will be imparted to liquid hydrogen as the working medium, and the expansion of this gas, through a suitable jet, will provide the impulse. The total length of the driving unit will be 42 m, and the diameter 8.3 m, and of the length the hydrogen tank will occupy 33 m. This unit will weigh 85 tons, while the total weight of the rocket will be 115 tons. The impulse will be 230 tons, this thrust lasting for 245 sec. Dr. W. Petri, of Bavaria, commenting upon these details, states that such rockets cannot be very far from the testing stage, but he is very far from similar optimism that we shall soon be able to use rockets in which the gaseous working medium does not have to be sent up in a tank with the rocket. In other words, he sees no immediate future for the ion rocket, about which the Americans have waxed so enthusiastic.



Laboratory scene at the English Electric's Atomic Power Centre, Whetstone

Industrial N-Centre Opened

English Electric's Atomic Power Centre at Whetstone, Leicester, focal point of research and development work for the English Electric—Babcock & Wilcox—Taylor Woodrow consortium, was recently officially opened by Lord Mills, Minister of Power. The ceremony was attended by over 250 guests who included leaders in industry, commerce, science, and diplomacy

ALTHOUGH the consortia building Britain's first four commercial nuclear power stations collaborate on much of their research and development work, they are far from being interdependent. In fact, in some aspects of their work they are downright competitive. And to be competitive they have to be independent. Thus, the large and extensive research centres the consortia and associated companies have established.

Nowhere is the spirit of independence more noticeable than at the English Electric Co.'s atomic power centre, Whetstone, Leicestershire. Many of the results obtained from work here is pooled : many of them however, will be applicable only to reactors of their own design. This is certainly true in the case of fuel elements, the study of which forms a large part of the work at Whetstone.

It is here that much of the research and development work on the 500 MW Hinkley Point station, which the English Electric are building in association with Babcock and Wilcox and Taylor Woodrow, is carried out. Investigation of the stability of the reactor core and components to be used in the station is still being undertaken, although the reactor design is virtually frozen. This work is done with the aid of PLUTO, one of the three analogue computers installed at the centre, and consists basically of measuring the simulated effects of accidents to and defects in various parts of the reactor core and its components. Any results which might affect the safety of a working reactor will be taken into account and the reactor design altered accordingly.

Also in connection with the Hinkley Point station is the building of a 85 ft deep pit for testing charge machinery. Fuel rods will be loaded and unloaded by means of a machine that carries out the job while the reactor is operating. To ensure its accuracy, the machine is being tested at Whetstone in a mockup of the reactor, the mockup being housed in the 85 ft deep pit.

AGR Studies

Naturally, much of the work at Whetstone is concerned with developments applicable to reactors of the advanced Calder Hall type—there are still some first generation gas-cooled reactor stations to be built in Britain, and English Electric have every intention of competing for the contracts for these. Work is in hand, however, both for studying aspects of the advanced gas cooled reactor (AGR), a prototype of which is being built by the UKAEA at Windscale, and of the organic moderated reactor system.

Ship Propulsion

English Electric recently concluded an agreement with Atomics International, a division of North American Aviation Inc., for the exchange of technical information in the organic field and a team of English Electric scientists and engineers is now in the States studying the Organic Moderated Reactor Experiment (OMRE) at Idaho Falls. In addition, the company is collaborating with Vickers Armstrongs Ltd. in an investigation of the possibilities of an organic moderated reactor marine propulsion unit.

The principal building that makes up the atomic power centre, the site

Background to Whetstone

English Electric was formed in 1918, by the amalgamation of four engineering firms. It has since grown into one of the greatest engineering complexes in Britain employing over 80,000 men and women and occupying 25 establishments in the United Kingdom and nine factories overseas. The original factory at Whetstone was built in 1942 for Power Jets (R & D) Ltd., the company established to further the initial development work of Sir Frank Whittle in the field of jet propulsion. Later, Whetstone became part of the National Gas Turbine Establishment. In 1953, the NGTE started to transfer their staff and equipment to Pyestock and the English Electric Co., began to take over, until in 1956 they were in complete occupation. The first activity to be moved from Rugby, the main works of the company, was the development work in the gas and steam turbine field. At the same time a central mechanical engineering laboratory was established. Early in 1955 the company set up the atomic power division

of which was originally the home of Power Jets (R & D) Ltd., the company formed to further the initial development work of Sir Frank Whittle in the jet propulsion field, is the atomic power development building. This brand new building houses the analogue computers, the toxic laboratories, where every type of fuel elements can be produced, and facilities for carrying out mechanical and heat transfer experiments and tests.

Largest in Europe

The computers, one of which will be, when completed, the largest of its kind in Europe, are for studying design aspects of reactors and reactor components. Two of them, PLUTO and SATURN, are designed by English Electric, the third, MARS, by Solartron Ltd. The centre is also equipped with a digital computer; in addition it can call in the use of the services of any other of the company's computer facilities—the company having seven digital computers elsewhere in the country.

Fuel elements of every known design and shape can be produced in the toxic laboratories, which are equipped for all machining and heat treatment processes necessary in the manufacture of uranium fuel elements. Facilities are also provided for the working of beryllium and magnesium alloys.

Many problems in a nuclear reactor relate to wear and lubrication under conditions of great heat and radiation. Rubbing surfaces may have to last for more than 20 years without any form of maintenance, much experimental work is therefore carried out under simulated reactor conditions to test the wear and tear of various reactor materials.

In addition extensive mechanical development work is carried out by the testing of prototype machinery such as fuelling machines, grabheads, control rod hoists and gas circulators. Equipment for creep, corrosion and thermal stability tests is also installed.

Fundamental Work

All work carried out in the atomic development building is backed by fundamental research work carried out in the Mechanical Engineering Laboratory, established in 1955. The work of this laboratory falls under four main headings—mechanics of solids; mechanics of fluids, heat and mathematics. In addition, there is a comprehensive chemistry and metallurgical laboratory.

Whetstone is predominantly a design and development centre. Nevertheless it includes a substantial production facility both to support the development and research programme and to manufacture the products designed and developed there.

Graphite Production

Facilities are provided for the production of graphite blocks and tiles to be used in the moderator and reflector at Hinkley Point. All the latest automatic machinery and handling equipment are installed to give the highest possible manufacturing efficiency, and there is a punched card system for accurate and prompt material control.

The machining has to be carried out with special precautions to prevent contamination of the graphite. Clean conditions must be ensured at all times and great attention paid to dust extraction and the clothing of the operatives.

Nearly all the equipment and apparatus for Hinkley Point is being made or has been made in the various regular production establishments of the consortium members and associated companies. The fuel charge-discharge machinery however, is being built at Whetstone, the nature of this equipment having necessitated the construction of a special workshop.

PLUTO, one of the three analogue computers installed at Whetstone. This one is currently used for work on the Hinkley Point fuel elements

Hot rolling of uranium in the toxic laboratories. These are equipped for the production, on an experimental scale, of any type of fuel element

PEOPLE... in the NUCLEAR NEWS

DR. A. S. McLEAN, who has been appointed director of the new health and safety branch of the UKAEA (*see* page 467) has been with the Authority since 1948, during which time he has held the post of

Dr. A. S. McLean

principal medical officer. For five years he sat on the Medical Research Council Committee on protection against ionizing radiation.

A New Zealander has been appointed new director of the International Atomic Energy Agency's Division of Isotopes. He is **MR. GEORGE E. ROTH,** who joined the Agency staff in February of this year as chief scientific officer. Born in 1908, Mr. Roth has studied physics, chemistry, pharmacology and biology and since 1935 has worked on biological effects of ultra-short waves microchemistry and radiation physics. In 1939 he was placed in charge of the Radiation Physics Laboratory of the New Zealand Branch of the British Empire Cancer Campaign Society and was responsible for the setting up of an extensive radiological physical service which covers all aspects of radiological work throughout the Dominion. As director of the Dominion X-ray and Radium Laboratory, Christchurch, he took a leading part in drafting and implementing radiation protection legislation. New Zealand was one of the first countries in the world which not only covered all aspects of radiation protection by legislation, but also provided the services of fully equipped and staffed laboratories to ensure adequate radiation protection was maintained throughout the country.

New deputy director of the mechanical section of applications branch, research and development department of the Central Electricity Generating Board is **MR. R. H. BURDETT,** BSc(Eng.), ACGI, AMIMechE, AMIEE, who was at one time nuclear systems engineer in the nuclear power branch of the British Electricity Authority. Aged 35 years, Mr. Burdett was educated at Banbury Grammar School and the City and Guilds College of London University. He was commissioned in 1943 in the Royal Navy as an electrical engineer officer. After the war he joined English Electric Co., Ltd., Stafford, as switchgear contracts officer, and in 1946, two years later he was appointed principal assistant engineer in the BEA's nuclear power division. He subsequently joined the department in the CEGB of which he has just been appointed deputy director.

Experts on scientific information from five leading nuclear countries recently met in Vienna to advise the International Atomic Energy Agency on the best methods of collaboration with Agency member states and the most effective ways in which the Agency can carry out its responsibilities for furthering the international exchange of nuclear energy information. The experts were **MR. MELVIN SHERMAN DAY,** assistant director for technical information service, the U.S. Atomic Energy Commission, **MR. R. M. FISHENDEN,** head of the scientific administration, UKAEA Atomic Energy Research Establishment, Harwell, **MR. RAYMOND GUILLOUX,** chief of the documentation service, French Atomic Energy Commission, **MR. DIMITRI M. SKOROV,** adviser to the U.S.S.R. Central Atomic Energy Board on scientific and technical information, and **MR. JOHN E. WOOLSTON,** technical information officer, Atomic Energy of Canada Ltd.

MR. CORNELIUS S. KIPFER, of the Argonne National Laboratory, has been appointed superintendent of the Central Shops, the Laboratory's facility for the engineering design and construction of special equipment used in nuclear energy research. He succeeds **MR. HERBERT V. ROSS,** who has taken up an appointment with Combustion Engineering Corporation, New York. Mr. Kipfer joined the Argonne staff in 1953, assuming the duties of an associate mechanical engineer. Later he became supervisor of the engineering section of Central Shops and in March, 1959, was named assistant superintendent of the facility.

Recently appointed vice-chairman of the GEC Ltd., and a managing director, **MR. A. L. G. LINDLEY** has been with the company since 1918, and has been responsible for the company's activities in the nuclear energy field since 1954. Educated at secondary and technical schools, Mr. Lindley's first major appointment was as chief engineer and director of British GEC, Johannesburg. In 1938 he became a director of the East Rand Engineering Co., also of Johannesburg. He accepted a directorship of the GEC in 1953 and became assistant managing director in 1957.

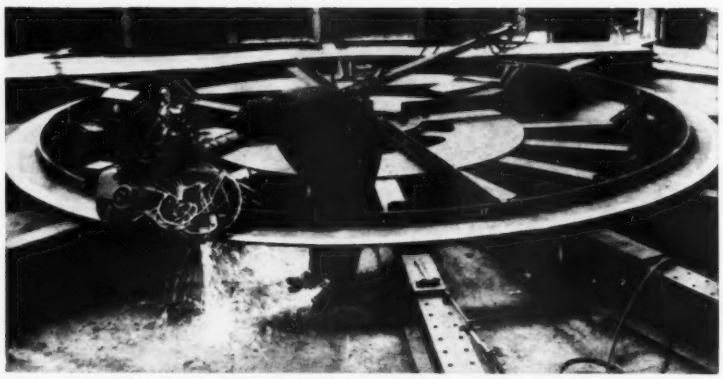
SIR ROGER MAKINS, the new chairman of the United Kingdom Atomic Energy Authority, takes up his duties on January 1st, 1960. At present, Sir Roger, who is 55, is Joint Permanent Secretary to the Treasury with Sir Norman Brook. As Assistant and later Deputy Under Secretary of State to the Foreign Office from 1947 to 1952, he was for a time head of an advisory body to the Government on nuclear energy policy. From 1953 to 1956 Sir Roger was British Ambassador to the United States. He returned to Britain to preside over the economic side of the Treasury. Sir Roger, who lives at Sherfield, Surrey, is married and has six children. Lady Makins is American-born and her father, the late Dwight F. Davis, was best known in Britain as the donor of the Davis Cup.

The new chairman of the Atomic Energy Authority, Sir Roger Makins, with his wife and Dwight, the youngest of their six children

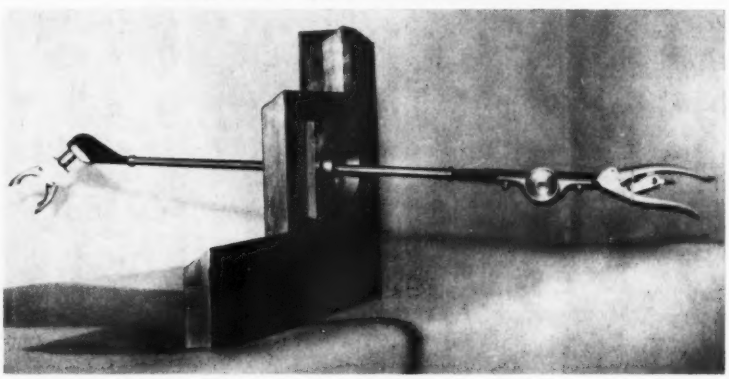
Equipment and Materials

Items published in this monthly feature are compiled from manufacturers' current literature. Readers requiring further information should use the form at bottom of the page. Manufacturers are invited to send literature or details of their products for inclusion in this feature.

A special purpose circle cutting machine has been designed and manufactured by British Oxygen Gases Ltd., for use in the fabrication of transverse hull rings of Britain's first nuclear powered submarine *Dreadnought*. The machine was designed and built as a special order for Vickers-Armstrongs (Shipbuilders) Ltd., of Barrow. The submarine transverse sections will be flame cut from steel, and will be circular in various diameters to give the submarine a cigar-like contour. The hull rings will be fabricated from four segments. Each segment will have a double bevel and nose preparation so that they can be welded together to form an annulus. Fabrication of these transverse hull rings will be completed by trimming the outside edge of the completed annulus by means of the special circle cutting machine. The machine is of the rotary self-propelled type. The carriage, which carries the five-nozzle cutting head, is provided with a radius and trammel bar revolving about a circular post. **(SR 1).**



(*Above*) **The machine designed by British Oxygen for cutting the circular transverse sections of the nuclear submarine** *Dreadnought*. (*Below*) **The EMEFCO Type T5 remote handling tool in its special universal ball mounting unit**



Modified Tool

Recently introduced by Nuclear Applications Ltd., is a modification of their world famous EMEFCO type T4 remote handling tool. Called type T5, it has been designed specially for use through a lead brick wall. Available in lengths of up to 8 ft the new tool is mounted in a special universal ball unit to enable it to be introduced into and withdrawn from screened chambers without difficulty. The head of the T5 is offset from the shaft at an angle of 45° and can be rotated through 360°. The claws can pick up anything from a needle to a beaker or isotope capsule. So that sensitive glassware cannot be broken through excessive pressure, the grip of the claws on the object being picked up is independent of the pressure applied by operator on the handgrip. The basis of the universal joint is a special split sphere machined in such a manner that concentric ridges in it form an effective joint and barrier against radiation. The sphere is accommodated in a cavity of a 2 in. thick lead brick with the usual 45° interlocking Vee edges. The cavity is so constructed to allow approximately 90° angular movements of the tool in all directions. The sphere itself is kept in place by means of a pressure cone having axial movement to the movement to the shaft. A rotating lock allows the pressure cone to be moved slightly forwards and backwards thus permitting either free rotation of the sphere or locking of the sphere at any angle. A locking mechanism to lock the axial position of the shaft is also provided. The space left by removing the mounted tool from a lead wall can be filled by lead plug. **(SR 2).**

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To: NUCLEAR ENERGY ENGINEER
147 Victoria Street, London, S.W.1

Please send further details of the following items in the EQUIPMENT and MATERIALS *feature for Sept., 1959*

Item No's ....

....

IS THIS ENQUIRY CONFIDENTIAL? | YES | NO |

Enquirer's Name .....

Position .....

Firm .....

Address .....

NUCLEAR NEWS

- **U.K.A.E.A's New Safety Branch** *(This page)*
- **Dungeness Station** *(Page 468)*
- **I.A.E.A. Finance** *(Page 469)*

A REVISED form of health and safety organization has been introduced by the United Kingdom Atomic Energy Authority. The principle that all Authority staff are responsible via the normal management chain of command for the safety of operations under their control remains unchanged and heads of establishments will continue to receive advice from their own specialist health and safety organizations. Separate health and safety organizations in each group headquarters are, however, being eliminated and a new Authority Health and Safety Branch is being established as part of the Headquarters organization of the Authority. Dr. A. S. McLean, principal medical officer at Risley, has been appointed to head the new branch with the title of Director of Health and Safety. The concept of an Authority Safety Branch was endorsed by the Fleck Committee which reported in January, 1958, on the organization for the control of health and safety in the Authority. However, at that time, the central function was limited to responsibility for problems of reactor safety and was undertaken by the Industrial Group Health and Safety Branch in addition to that Branch's local responsibilities. This form of organization was dictated by the acute shortage of staff to which reference was made by the Fleck Committee and which made it necessary for the majority of key staff to perform a dual role, viz.: (1) to advise on the control of day-to-day operations at the Authority's establishments; and (2) to contribute to the formulation of policy both inside and outside the Authority. Since the Fleck Committee reported, redeployment of staff and a determined recruitment campaign has now made possible the introduction of the revised form of organization which is designed to secure a greater concentration of effort. The new Authority Health and Safety Branch will collaborate with, and have the assistance of, the Health and Safety staffs in the Authority's establishments and will have three main functions:—

(*a*) To advise the Authority on the formulation of their health and safety policy and to disseminate this policy for application by Heads of Groups and Establishments;

(*b*) To apply this policy to the assessment and inspection of reactors and plants (including laboratories); and

(*c*) To provide the focal point from which the Authority's external relations (both technical and political) in the health and safety field will be conducted.

Under Dr. McLean's direction, the technical work of the new Branch will be undertaken by two Divisions as follows: (i) *A Safeguards Division*, headed by Mr. F. R. Farmer and located at Risley. This Division will be concerned with the safety of reactors, plant and laboratories; and (ii) *A Radiological Protection Division*, headed by Dr. W. G. Marley, OBE, and located at Harwell. This Division will be concerned with all aspects of the health and safety of Authority employees and neighbouring populations, and will advise the Safeguards Division on the standards of human protection to be applied in the evaluation of the safety of nuclear installations.

Highlights From U.K.A.E.A. Report 1958-59

Work started during the year under review on construction at Windscale of the prototype advanced gas-cooled reactor (AGR) on which the second generation of nuclear power stations will be based. A zero energy reactor, to be known as HERO, is to be built to complement the work of the AGR prototype.

The last of the four Calder Hall reactors became critical during the year and the first at Chapelcross came into use for electricity generation.

At Springfields, the Authority's uranium factory, the millionth uranium fuel rod was produced, while at the Authority's Isotope School, Harwell, the thousandth student was enrolled.

During the year the Authority's staff increased from 30,341 to 35,260. At a press conference, Lord Plowden, retiring chairman of the Authority, said attempts were to be made to reduce the high rate of staff increase experienced by the Authority.

Work on thermonuclear reactions continues. Much work remains to be learned about the properties of plasma and present work in research is directed to studying ways of forming, containing and heating plasma and to diagnosing the behaviour of the constituent particles under a variety of conditions.

At the Atomic Weapons Research Establishment, Aldermaston, studies have been centred around a proposed experimental device called HITEX (High Temperature Experiment) which would work on the same principles as the DCX machine of the Oak Ridge National Laboratory in the U.S.A.

No decision has been made on where to move the Authority's thermonuclear research.

Authority establishments were visited by over 60,000 people during the year.

The Authority's estimates for 1959-60 were approved by Parliament for the net sum of £92,433,010, £13,391,010 less than the estimates for 1958-59.

Isotope sales during the year were worth £800,000, compared with £650,000 in the previous year. Sixty per cent. of the sales were abroad.

On March 31st the Authority had 23 reactors in operation, under construction and planned.

Tribute is paid to the late Sir Claude Gibb, chairman of the Nuclear Power Plant Co., Ltd.

The report refers to the difficulties and limitations experienced with ZETA, the Zero Energy Thermonuclear Assembly with which much of British research into fusion has been carried out. It says that there is need for a more radical attack on the problems of current and magnetic field distributions and continues to say " design studies have been carried out for a system capable of operating both at much higher pressures and also at faster rates of current rise." From these studies there has apparently evolved the design of a machine ICSE, Intermediate Current Stability Experiment, which the Authority is to build at its new fusion centre. This machine, which will cost more and be larger than ZETA, will consist of a torus so rigged that the plasma losses will be kept to a minimum. Work on the design is being undertaken by a team from Harwell under the direction of Sir William Penney, who is the new Member for Research of the Authority.

Sea as Dump

SUBSTANTIAL progress was made in the work of the international panel of experts on radioactive waste disposal into the seas, which recently met in Vienna. The term radioactive waste has been used to designate the material originating from various processes connected with the peaceful applications of atomic energy for which there is no immediate use. In present practice one is largely concerned with the storage of such unused radioactive material for which reasonably satisfactory procedures have been developed. It is even possible that eventually such material may be used in some fashion to aid mankind. The panel is concerned with recommending measures that may be necessary to ensure safety of the seas from small amounts of radioactive material which may not be provided for by present storage methods. It is expected that the panel will complete its studies and make a report before the end of the year.

Dungeness Station

OFFICIAL approval has been given for the construction of a nuclear power station at Dungeness. The station, which will be operated by the Central Electricity Generating Board, will have an output of 500 MW. The decision to build a station on the site at Dungeness met with public objections on the grounds that the chosen site was of unusual scientific character and its isolated and unusual character should be preserved from development. In addition, the Nature Conservancy had proposed to establish a nature reserve there. At the public enquiry at which the objections were lodged and discussed, it was shown that the station site was only 10 per cent. of the area of the proposed reserve. The inspectors came to the conclusion that provided safeguards were adopted by the CEGB to prevent contractors and others interfering with the rest of the area, the botanical and entomological interests would not be seriously affected. In giving his approval to the station, the Minister of Power, Lord Mills, said there were three points he particularly had in mind. These were (*a*) the growth in the demand for electricity, which doubles every 10 to 12 years, will render increasingly necessary the use of nuclear power in certain parts of the country in addition to available coal supplies; (*b*) the nuclear power programme has brought into being a major new industry and its implementation is of great importance to the maintenance of Britain's lead in this field; (*c*) even if there were no nuclear programme it would not be practicable to continue indefinitely to site new power stations on the coalfields because of the very large quantities of cooling water required, and consequently it would still be necessary to consider sites like Dungeness.

Be Company

IMPERIAL Smelting Corporation, the U.K. subsidiary of Consolidated Zinc Corporation, and The Beryllium Corporation of Reading, Pa., U.S.A., recently announced the formation—subject to Exchange Control consent—of a new, equally-owned British company, Consolidated Beryllium, Ltd., which Imperial Smelting will manage. The new company will produce nuclear grade beryllium metal and beryllium-copper master alloy as raw materials for sale to fabricators both in the U.K. and in Europe. It will operate the beryllium metal plant now under construction at Avonmouth and due to start production later this year. The new company will also commence immediately the erection of a beryllium-copper master alloy plant at Avonmouth to supply an already established market for this material in the U.K.—to which the Beryllium Corporation has been exporting for more than a decade. Beryllium-copper is used in the manufacture of current-carrying springs for electrical and electronic equipment, and for use in many other industries. The beryllium content greatly improves mechanical properties while retaining conductivity. In view of the possible future requirements of beryllium metal for use in the U.K. nuclear power reactor programme, the new company is planning the largest beryllium metal plant in the world, to enable construction to begin without delay as soon as a large scale demand develops. In the meantime the American partner will provide any metal required in excess of the current capacity of Consolidated Beryllium, Ltd.

A1—OMR Study

DESIGN of an organic liquid cooled and moderated nuclear reactor to propel a 60,000 deadweight ton tanker ship has been completed by Atomics International, a division of North American Aviation, Inc., for the U.S. Atomic Energy Commission. The purpose of the design study was to determine specifications and operating characteristics for an organic reactor propulsion system to provide 30,000 shaft h.p. The design study includes estimates of costs, time and manpower required to design and build the reactor plant. Feasibility of using an organic reactor for marine propulsion was indicated in an earlier study completed in 1957 by Atomics International for the Commission.

NUCLEAR NEWS

U.K. Firm in Italy

THE Italian Comitato Nazionale per le Richerche Nucleari has acquired from the 85-year-old British water treatment firm, William Boby & Co., Ltd., an electrodialysis stack for experiments in decontamination of nuclear effluents. Boby's, whose design office and works are at Rickmansworth, Herts, have received world-wide attention recently for their pioneer work in co-operation with Dutch and other foreign research scientists into the purification of water and other liquors by electrical processes.

For The Philippines

THE United States Atomic Energy Commission have formally signed a letter of commitment approving an economic grant of up to $500,000 (£166,000) to the Philippine Government for the purchase of a U.S. General Electric open pool research reactor. The funds will be made available under the terms of President Eisenhower's "Atoms for Peace" programme. Dr. Paulino J. Garcia, chairman of the National Science Development Board, signed the agreement on behalf of the Philippine Government. General Electric will supply a 1 MW reactor which will form the heart of a nuclear research centre the Philippine Government is constructing for the University of the Philippines at Diliman, Quezon City, eight miles north-east of Manila. Construction of the reactor will begin immediately and is scheduled to be placed in operation by the autumn of 1960.

Factory Extension

AN extension to the Northampton factory of Plessey Nucleonics, Ltd., was opened recently by Sir John Cockcroft, OM, FRS, formerly Research Member of the United Kingdom Atomic Energy Authority, and now Master of Churchill College, Cambridge. On arrival at the factory, Sir John was welcomed by Mr. A. G. Clark, chairman of The Plessey Co., Ltd., Dr. Denis Taylor, a director and general manager of Plessey Nucleonics, Ltd., and other Plessey group directors. After the opening, Sir John toured the factory at which are being manufactured burst slug detection equipment for nuclear reactors, health and plant safety apparatus and products used in nuclear instrumentation. Currently in production are burst slug detection systems for Hinkley Point and Latina (Italy) nuclear power stations. Burst slug detection equipment is also in production for DIDO, PLUTO and DMTR research reactors in this country and for the German research reactor at Karlsruhe. During the tour, visitors saw a demonstration of a new plutonium monitor developed for the detection and location of minute quantities of plutonium which may accidentally enter the human body.

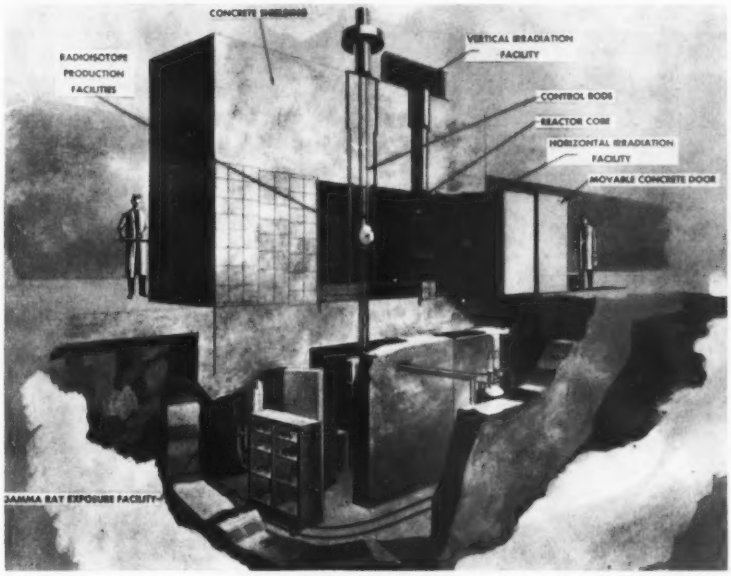
Private N-Fuel

ROLLS-ROYCE, Ltd., is building an experimental and development factory at Raynesway, Derby, to fabricate fuel elements for the pressurized water reactor of the Royal Navy's nuclear powered submarine *Dreadnought*. The plant is expected to cost at least £1m. The fuel element production process will be taken over by Rolls-Royce after the raw material has been extensively treated at the Atomic Energy Authority's Springfields and Capenhurst plants. The final stages of the fabrication of the fuel elements will include manufacture of the containers.

Radiation Research

A RESEARCH project which may have an important bearing on the understanding, diagnosis and treatment of radiation sickness as well as on the possibility of preserving food and drugs by irradiation will be carried out in London under a contract awarded by the International Atomic Energy Agency. The research will be conducted at the Chester Beatty Research Institute under the guidance of the Institute's eminent anzymologist, Dr. Peter Alexander, and in collaboration with the Microbiology Department of the Imperial College of Science and Technology, Kensington. The Agency has granted $6,000 for the first year of the project. The object of this research is to contribute to an understanding of the reasons why microorganisms vary widely in their sensitivity to ionizing radiation and to examine how they can be made more sensitive to radiation than they normally are. An understanding of the natural reasons for the variations in radio-sensitivity would be of value in the study of some fundamental problems of radiobiology and radiation protection.

Medical Treatment Reactor



Sectional drawing of a 50,000w reactor designed by Atomics International, a division of North American Aviation, Inc., for the Walter Reed Army Medical Centre in Washington, D.C. The reactor will be used for biological research and for medical treatment of hospital patients. It is a " solution " type reactor which uses about seven gallons of uranyl sulphate solution, highly enriched in U-235, as fuel. The solution is contained in a 16 in. diameter stainless steel sphere which is installed inside an 8 ft × 5 ft × 5 ft stack of graphite " logs " shielded by 5 ft of high density concrete. Control rods are of boron-carbide. The reactor is provided with several irradiation exposure facilities designed specifically for biological research. Two irradiation columns, one leading from the top of the reactor, the other horizontally from the side, will permit exposure of large objects to streams of neutrons from the reactor core. Another facility will permit materials to be irradiated in a tube penetrating the core itself where radiation will be the strongest. Several other exposure tubes are located near the core.

I.A.E.A. Finance

A TOTAL expenditure budget for 1960 of $8,233,000 for the furtherance of peaceful uses of atomic energy will be recommended for adoption by the General Conference of the International Atomic Energy Agency which is scheduled to open its third session in Vienna on September 22nd. This figure has been decided upon by IAEA's Board of Governors which has devoted many meetings of its current session to a scrutiny of the Director General's programme and budget proposals. The figure of $8,233,000 represents an increase of $708,000 over 1959. The total is made up of $5,843,000 for the regular or assessment budget and $2,390,000 for the operational budget which is financed from voluntary contributions and the United Nations Technical Assistance Programme. The main increases suggested in the Agency's activities for 1960 relate to fellowships and technical assistance. Other estimates showing some increases include those for the organization of seminars and conferences, the exchange of information, the award of research contracts and the calling of advisory panels. The Board, although insisting that 1960 should be a year of budgetary consolidation, recognized that in these fields an acceleration of the substantial current activities was needed in order to meet the needs and requests of the majority of member governments. The suggested secretariat staffing for 1960 amounts to 239 professional and 271 general service posts. The corresponding figures for 1959 were 221 and 244.

Solar Power

LONG mission satellites and manned space vehicles of the future will be able to tap a limitless supply of electric energy by means of a solar-powered thermoelectric generator, Westinghouse and Boeing engineers recently announced at a demonstration of a solar-powered thermoelectric generator. This weighs 3 lb and measures 20 in. in length. It is capable of converting the energy of the sun into 2.5w of power—enough to operate a radio transmitter broadcasting a strong signal back to earth.

Teaching Problems

EDUCATIONAL problems in connection with the development of peaceful uses of atomic energy were discussed at a seminar recently organized jointly by the International Atomic Energy Agency (IAEA) and the United Nations Educational, Scientific and Cultural Organization (UNESCO) at the French centre for nuclear research, Saclay. About 60 scientists from 30 countries took part in the discussions which were presided over by France's High Commissioner for Atomic Energy, Professor Francis Perrin. Separate sessions dealt with the role of universities, engineering colleges, nuclear research centres and international organizations in the education of nuclear scientists and technicians. The necessity of interesting members of university and technical college faculties in various aspects of nuclear science and technology was discussed, as also was the need of training more health physicists and of introducing nuclear science at the secondary school level.

Office Move

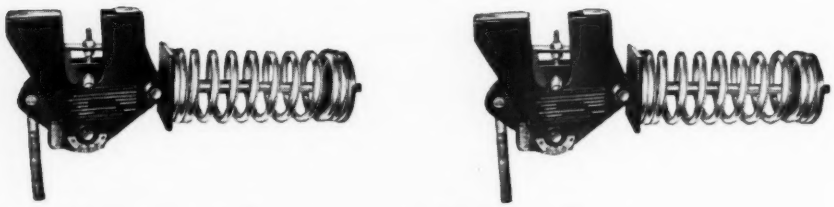
EVERSHED & VIGNOLES, Ltd., manufacturers of instruments and electronic control equipment, have moved their Scottish Area office to larger accommodation at 30, Rutland Square, Edinburgh, 1. The telephone number remains as before at Fountainbridge 3056.

N-Physics Machine

THE 50 MeV proton linear accelerator at the Rutherford High Energy Laboratory, Harwell, has come into operation. It is to be used for nuclear research by physicists from universities, the Atomic Energy Authority and a resident team based at the Rutherford Laboratory. When in full operation it is expected to have a proton beam intensity many times greater than other accelerators of this kind. Because of the high intensity and very well defined energy it will be possible to do experiments of great value in the study of the interaction between nuclear particles. The main parts of the accelerator were designed and constructed for the Atomic Energy Authority by Metropolitan-Vickers, Ltd. Research Establishment.

Reactor Plug

Shown here being lowered into place is the 106-ton rotating-shield plug for the Enrico Fermi Atomic Power Plant, Lagoona Beach, Michigan, America's first full-scale fast-breeder nuclear power plant. The stainless steel plug precision machined to mirror-like finish acts as the closure for the reactor vessel whose shell weighs 91 tons. Both the vessel and the plug were built by the Chattanooga Division of Combustion Engineering, Inc.



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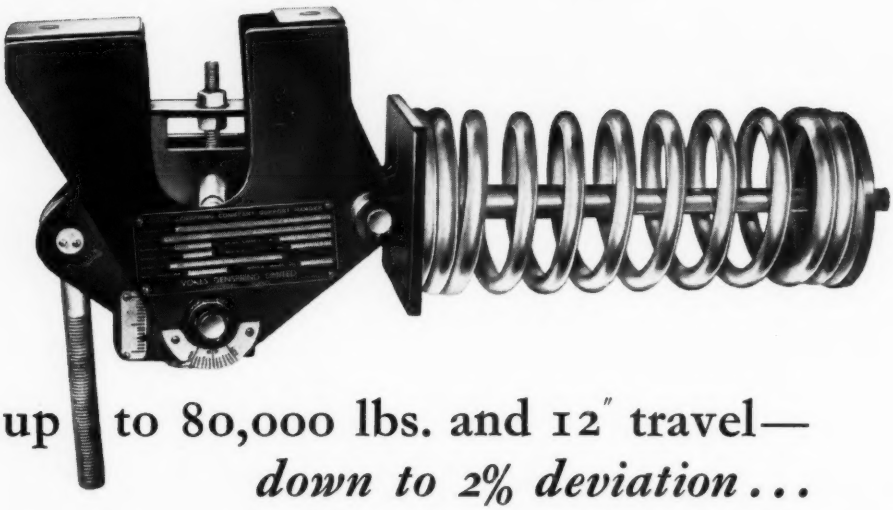

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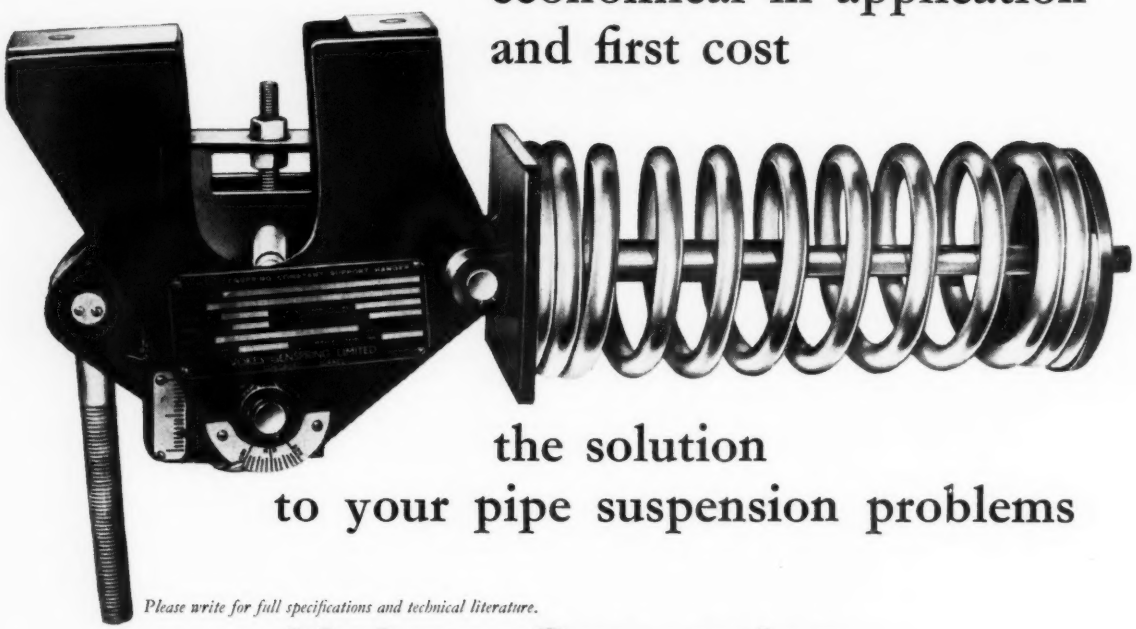

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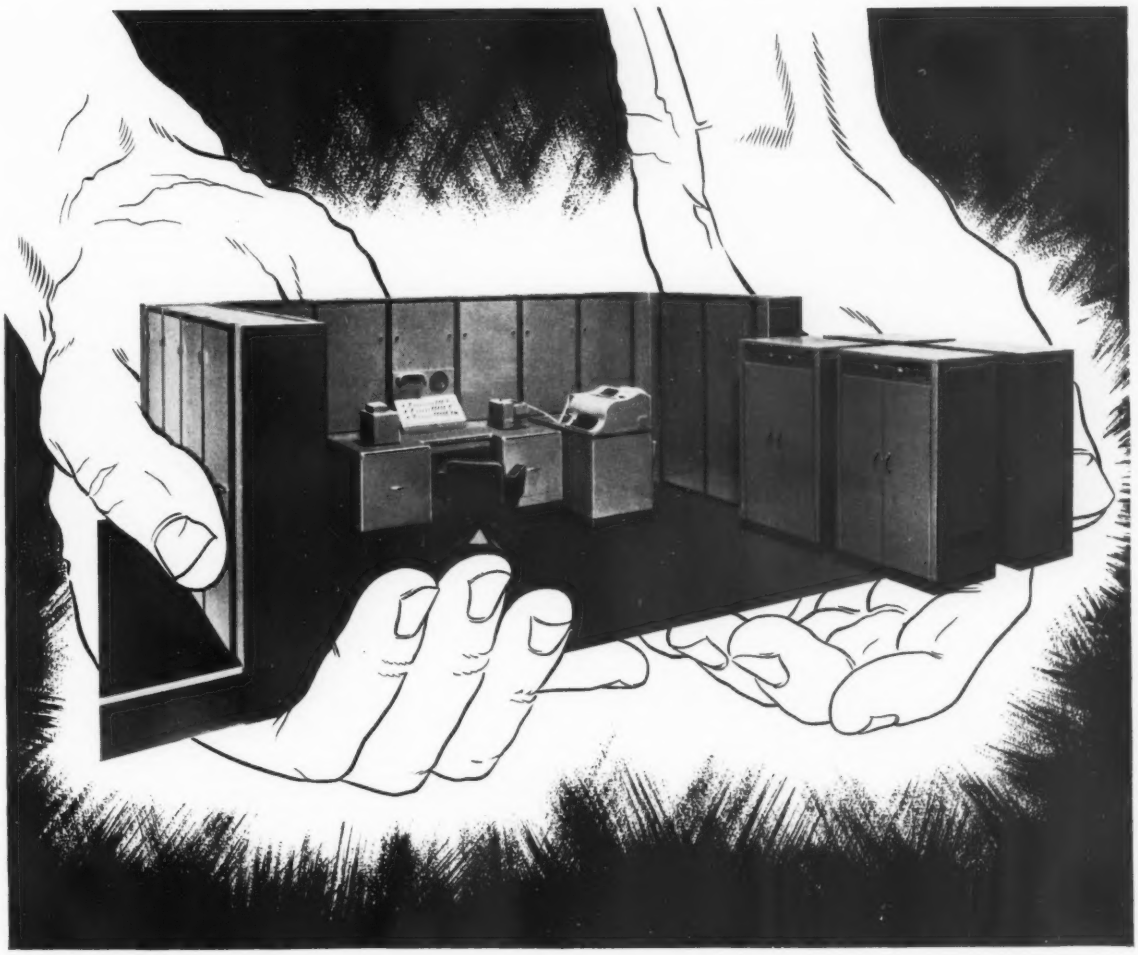

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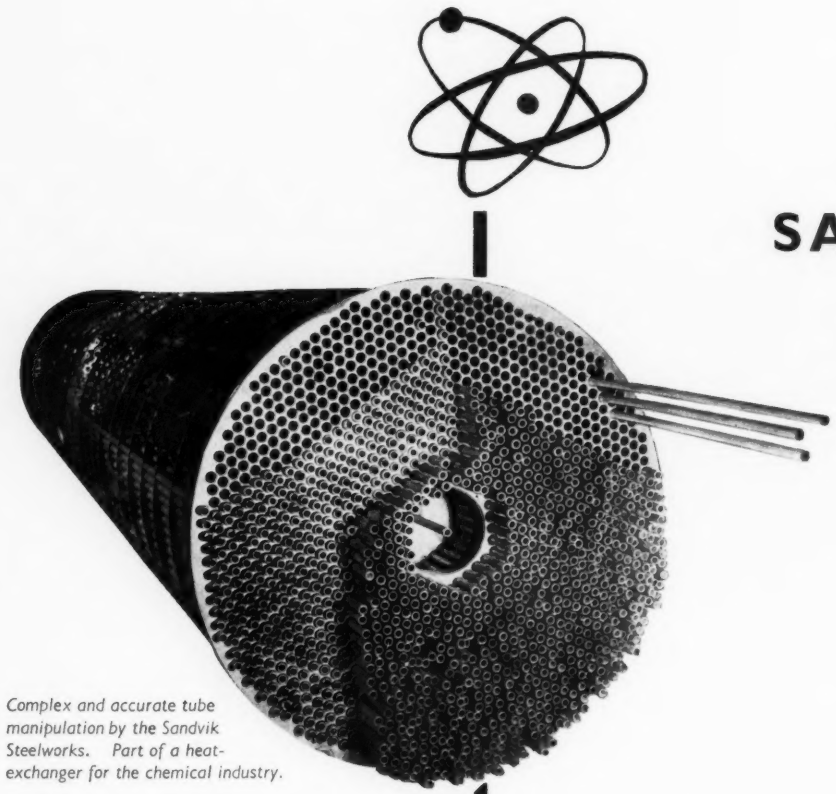

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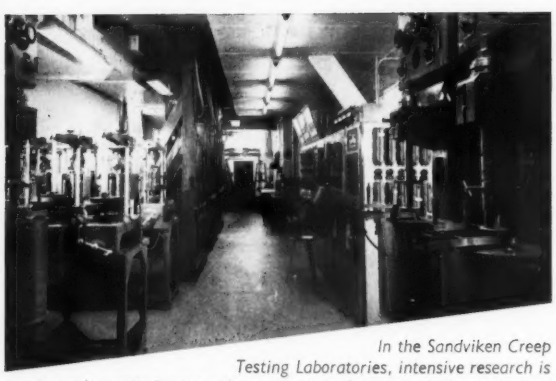

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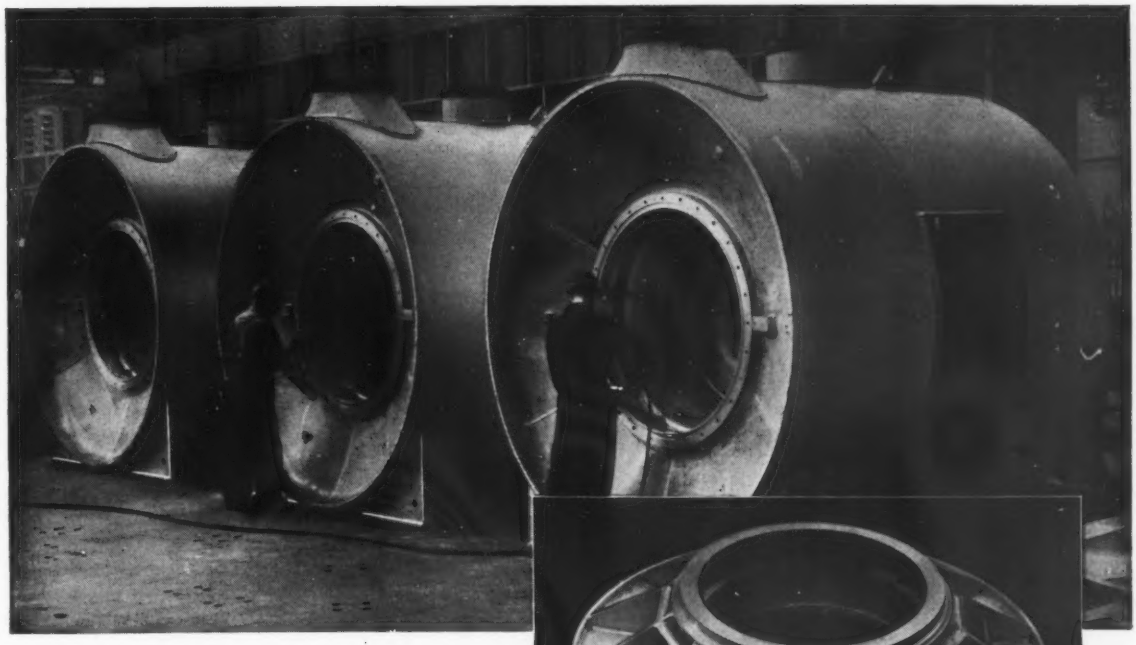

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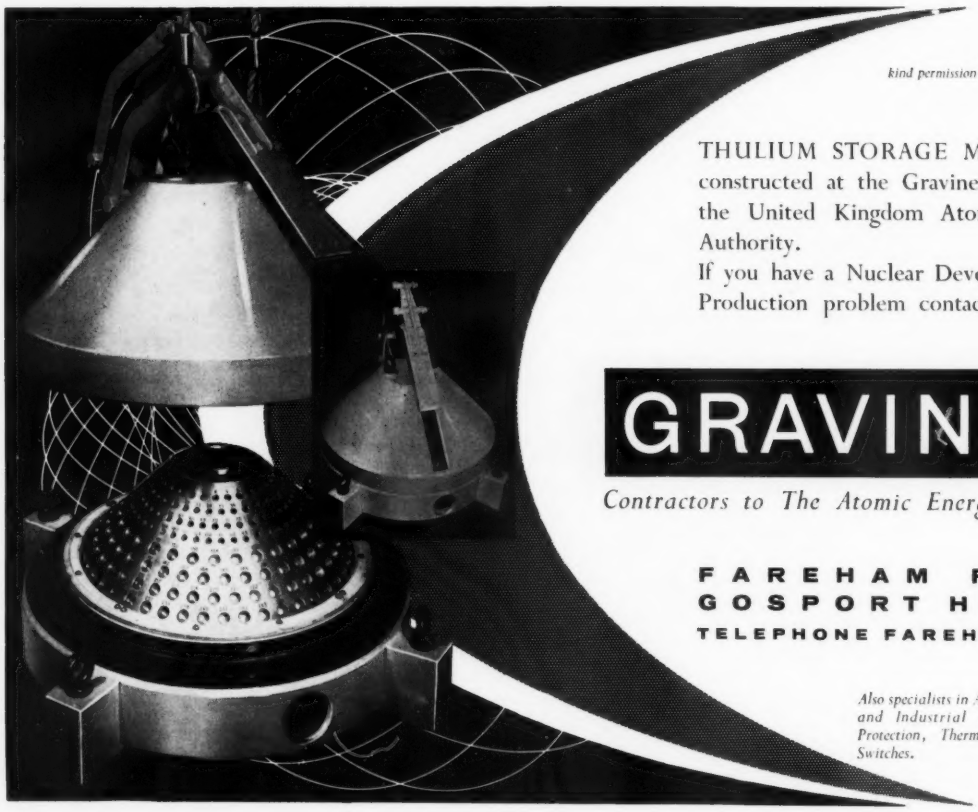

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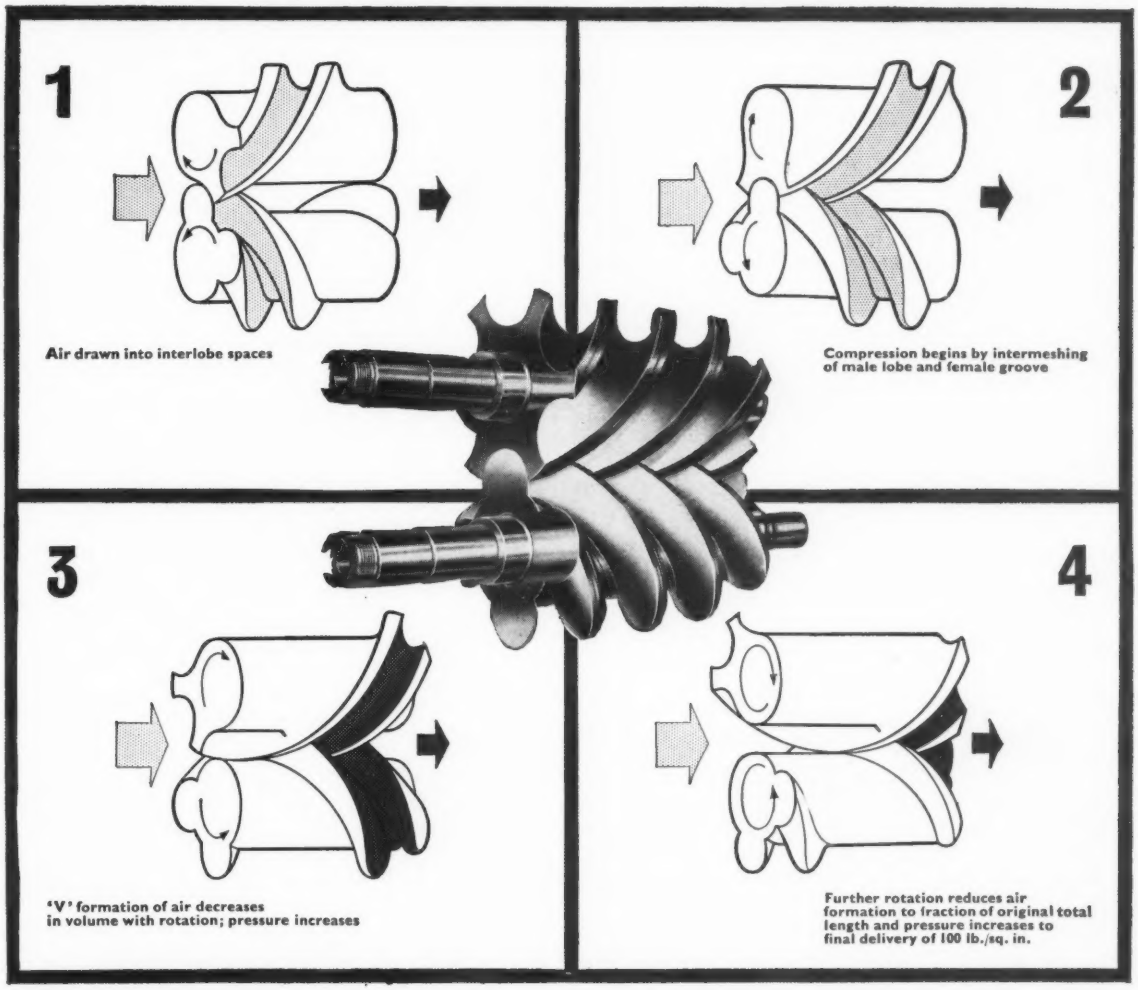
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